University of Alberta

Innovation through Inspiration: Looking at nature and biomimicry as a source of inspiration for industrial designers

by

Hussain Mohammed Almossawi

A thesis submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Masters of Design
in
Industrial Design

Art & Design

Fall 2013
Edmonton, Alberta

Innovation through Inspiration:

Looking at nature and biomimicry as a source of inspiration for industrial designers

Hussain Mohammed Almossawi

A support document in partial fulfillment of the Master of Design degree

Industrial Design
Department of Art and Design
University of Alberta

August 2013

Dedicated to my wonderful parents,

for all their love, support, and encouragement.

Table of contents

Acknowledgments

I would like to give a special thanks to the following people at the University of Alberta, for their advice and guidance while being at the University, Tim Antoniuk, Robert Lederrer, John Nychka.

I would also like to acknowledge the amazingly talented, fun, creative, and humble people at Nike Inc., who gave me a lot of their time to conduct interviews with them and walk away with a handful of great advice from each one of them that will always serve me well, and for that I am really grateful: John Hoke, Tinker Hatfield, Andy Caine, Denis Dekovic, Doug Wilkins, Mark Miner, Michael Hui, Russell Stott, Thomas Walker, Jessi Small, Michael Leon, Allan Brabo, Richard Clark, Jason Mayden, Jason Taylor, Wilson Smith, Michael Shae, Toby Hatfield, Leo Chang, Eugene Rodgers, Erick Goto, Matt Holmes, Howard Lichter, Cubby Golden, Jarrett Reynolds, David Creech, Rob Dolan and Angelo Colletti.

Finally, I wish to thank my parents, brother, and family for all their help, support, and encouragement.

List of Figures

1. Introduction

If you are seeking inspiration, just open your eyes. The world is teeming with new ideas, uncultivated material, and uncharted pathways to innovation. If you really look around, you will often find inspiration in places where you least expect it. Inspiration is the key to developing any new, big idea or innovation. As designers, we must nourish our creativity and imagination with regular doses of inspiration, and we must realize that there are many ways of being inspired. We can find inspiration by talking with people and listening to their ideas, by travelling and experiencing new cultures, or simply by seeking out the shine of excellence in everyday encounters. Perhaps the most boundless and abundant source of inspiration available to designers is nature.

The earth has existed for more than 3.8 billion years, and is home to rich, diverse, and highly adaptive eco-systems. The earth's eco-systems are able to function and evolve harmoniously because it is near-perfect in its design. It is efficient, balanced, and self-sustaining. Human beings can learn a lot from nature, and that's where biomimicry reveals itself to be the most valuable resource a designer has at their disposal. The concept of biomimicry is based on the practice of turning to nature for answers to problems we are trying to solve through design. Biomimicry is an essential tool for designers, especially at a time where environmental concerns are growing at a rapid pace. We are seeking greener designs, products that produce less waste, use less energy, and are made from reusable materials. Biomimicry may provide an answer to these concerns. The range of possibilities it offers is vast. Biomimicry can be used to help a designer with simple and straightforward tasks, such as finding the appropriate color or pattern for a specific design, or it can be used in more complex ways, such as mimicking an entire eco-system.

This thesis explores the importance of inspiration in developing innovative solutions in the field of design while maintaining a larger emphasis on nature as a source of inspiration, specially through biomimicry. It presents research, examples and case studies that explore how inspiration leads to innovation, especially within the context of biomimicry. I discuss and analyze my own experience as an intern at Nike, Inc., and how learning from top designers in the field has expanded my perspective, and ultimately compelled me to travel throughout the Middle East in search of inspiration and new paths to innovation. This thesis also explores the different ways nature has inspired and resulted in important innovations, and how the field of biomimicry has developed into its current manifestation. It also looks to the future of this exciting field, and considers the untapped potential and innovations that lie ahead.

I believe biomimicry is a valuable answer to the challenge of crafting a sustainable future. Waste and inefficiency are global problems that affect all people in all fields. It is the responsibility of designers to rethink and reform the faulty systems and structures that govern our daily existence. My intent is to contribute to the expansion of this important field by creating a framework within which industrial Designers can find solutions to design problems by way of biomimicry. My primary objective in developing this approach is to explore how different functions found in nature can address a wide range of design problems and create a concrete foundation or framework that future designers can build upon. The first step requires the designer to actively seek out natural functions that could be applied to modern product design. Then, the designer will hand pick several of these features and apply them as potential solutions to the design problems in question. Two of these problems will be developed into case studies, and be analyzed carefully in hopes of gaining a deeper understanding of the innovative potential of biomimicry. In addition, I will examine how biomimicry influences the aesthetic features of a design, such as shape and color, and will explore how nature works to enhance the story that lies behind the "product". The new ideas that come out of this experiment will be presented as propositions to be tested by a team of experts and to see if there are useful methodologies.

In short, this thesis will provide a comprehensive background of how biomimicry has developed, and how my own exploration and thinking has led me to the field. Along the way, it will illuminate the essential ingredients to success: inspiration and innovation. This project is a first step in forging new paths and creating innovations that will revolutionize the field of industrial design, by way of biomimicry.

2. Literature Review

2.1 Defining Biomimicry

Biomimicry is the study of nature in order to develop sustainable and innovative solutions to human problems. This concept can be applied to various fields, and it is especially relevant in the field of design (Ternaux, 2012).

The term biomimicry was first used in 1964, as a general term referring to any living form imitating another living form. What we understand as biomimicry today was called "bionics" at that time, and was defined as the study of processes and behaviors that nature employs to resolve and overcome problems (Boks and Volstad 2012). It is largely thanks to the work of biologist Janine Benyus that biomimcry has taken precedence over bionics, and that ecological sustainability has become one of the defining tenets of biomimicry (Benyus, 1997).

Although "biomimicry" is a fairly new term, it is not a new concept. Mankind has been looking to nature for inspiration and wisdom since the beginning of time (Eadie et al, 2011). For instance, the Chinese attempted to create artificial silk more than 3000 years ago (Vincent et al, 2007). Leonardo da Vinci studied the physiology of fish and birds to design ships and planes. The Wright Brothers followed in Leonardo's footsteps and continued studying birds only to realize that they glide on currents rather than just relying on flapping their wings. Soon after, they invented the first working airplane (Eggermong, 2007).

With the twentieth century development of radical new technology, man has looked to nature for guidance less frequently. In her 2012 book *Industry of Nature: Another Approach to Ecology,* Elodie Ternaux discusses how, for years, Mankind has turned away from nature and done things in a manner that best suits the needs of man, without thinking of the consequences or larger effect on the environment. Mankind is notorious for trying to dominate other living species as well as nature itself, rather than looking to nature as a source of knowledge and inspiration. But that is starting to change. Mankind has realized once again that nature offers a fantastic terrain for creativity (Ternaux, 2012).

Bio-inspired innovations have started to spark a great amount of interest in recent years because, for the first time in history, we possess the right number of resources and the expertise not only to observe nature, but to start cracking its immense secrets. Scientists, designers and experts from different fields and disciplines are able to collaborate with greater ease and efficiency, gaining access to crucial

knowledge of how nature has built and sustained a multitude of different eco-systems over the past 3.8 billion years (Boks and Volstad 2012). Mankind has started to use new technologies to observe nature more closely and to develop innovations either by copying directly from nature, or by deriving inspiration from patterns and processes in nature (Ternaux, 2012).

Ternaux (2012) states that although an ongoing debate has been emerging in the design world about the quality of natural versus artificial materials the idea exists that a natural material or something coming directly from nature is "better" than a man-made material. That is an incorrect assumption that should be changed. A piece of wood and a piece of plastic are both products of nature. While wood is taken directly from nature and used in its unaltered natural form, a substance such as plastic is created when Man converts natural products into a more advanced and beneficial form. Progress is the ability to take raw materials and convert them into something new, with greater benefits. This is one of Mankind's great, unique skills, and a defining feature of biomimicry (Ternaux, 2012).

Rasha El-Zeiny, a professor of interior design at Minia University in Egypt, defines biomimicry as more than the reproduction of a single natural object or system, and beyond the simple design of a sustainable or "green," product. El-Zeiny calls biomimicry a meticulous examination of a specific organism or ecosystem and its underlying design principles, followed by an even more precise and mindful application of these principles. She differentiates the act learning *from* nature from the practice of merely learning *about* nature (El-Zeiny, 2012). Many people can study the multitude of patterns that occur in the natural world; it is a living encyclopedia of ingenuity. The challenge that biomimicry faces, then, is the successful application of these patterns when devising solutions to human challenges. Janine Benyus, founder and president of the Biomimicry Institute, agrees. She states that, "nature is imaginative by necessity, and has already solved many of the problems we are grappling with today" (Benyus, 2008). Biomimicry expert Penny Stamps describes this process as neither copying or mimicking nature, but rather emulating it (2010).

Victor Papanek, a highly respected designer and educator, also supports this view; "Nature is a veritable expert in sustainable development". Ternaux (2012) agrees, and notes that we are very good at imitating certain aspects of nature, but when it comes to using natural resources, we need to be more cautious to avoid completely draining the earth of these resources. According to Ghahremani (2012), in order to truly emulate nature, we must be as frugal as nature is with our resources, using only what is free and nearby and replacing what we take so it can be used by the next generation. The practice of using local resources mindfully, according to availability, will maintain equilibrium in the natural world

and avoid endangering any species. It is obvious that nature is far more experienced and perfect than any creation of mankind. With 3.8 billion years of "experience", we can turn to nature for all kinds of inspiration and solutions, by studying its forms, structures, systems and functions. This approach could enable us to advance in a more sustainable manner. Sustainability requires us to possess great capacities of retention, observation, understanding and the willingness to implement real change in the way we think and approach problems. If we make the effort to sustain our resources, the eco-system as a whole will flourish, benefitting both mankind and nature for years to come (Ternaux, 2012).

Benyus (2008) talks about the following principles that characterize nature's successful sustainability In her book *Observing Nature*:

- A major source of energy for Nature is solar energy.
- It uses only the amount of energy that it needs.
- It matches form to function.
- It recycles everything.
- It bets on diversity.
- It works with local expertise.
- It limits its own internal excesses.
- It uses constraints as a source of creativity.

Sustainability has been a concern as far back as the fifteenth century, when Leonardo da Vinci encouraged and invited us to look to nature to learn how to become a sustainable society (Eggermong, 2007). As Leonardi da Vinci said, "Man's engineering can imitate many inventions, thanks to the use of various instruments contributing to the same goal. However, he will never make them more beautiful, more simple or better adapted than those of nature because, in its inventions, nothing is missing and nothing is unnecessary".

2.2 Approaches & Processes

Benyus (1997) explains that the starting point of any design project is from one of two places. We either start by defining and identifying a problem, and then we proceed to look for how nature solves similar problems (the "problem-based" process), or we discover a new function or feature in nature, and then we proceed to find a situation to which we can apply this new technique (the "solution-based" process).

When utilizing the *problem-driven* process, designers must clearly identify design-based problems, and then biologists must turn to the natural world to find a living organism that embodies a similar problem. From there, biologists and designers work together to develop a man-made solution based on the solution they discover in nature. In order for this approach to be effective, designers must have clearly articulated goals and design parameters (Perdersen & Storey, 2007). Helms (2006), a researcher at Georgia Tech University, who also closely worked with the Center for Biologically Inspired Design, breaks the *problem-driven* process down into six steps:

- Step 1: problem definition
- Step 2: reframe the problem
- Step 3: biological solution search
- Step 4: define the biological solution
- Step 5: principle extraction
- Step 6: principle application

Despite these clearly defined steps, the progression of the problem-based process is not linear (Vattam & Goel, 2009). Often, later output provides iterative feedback for previous steps, and the previous steps then go through a refinement process (Helms et al, 2009). Architect, author and designer William McDonough, whose work focuses on sustainability, suggests that the looping-back quality of the problem-based approach might be a productive way to begin transitioning the environment in which we currently live into a more effective and sustainable environment (McDonough, 2002).

The *solution-based* approach relies on prior biological knowledge rather than the existence of a specific problem. A collaborative design process develops when scientists and designers use relevant biological and ecological research to enhance and expand design. This approach has many advantages, as it is not limited by the parameters of a previously-existing problem. This freedom often results in radically new

technologies, unprecedented progress and true paradigm shifts within the design field (Vincent, 2005). The major disadvantage of this approach is that it relies on previously-conducted biological research. All stages of the research must be complete, and then it needs to be identified as relevant to a specific design context, which drastically slows down the innovative process. It also demands that biologists and ecologists possess adequate understanding of how their research can affect and inspire innovation in the design field, which is not always the case.

Helms breaks the *solution-based* process down into 7 steps:

- Step 1: biological solution identification
- Step 2: define the biological solution
- Step 3: principle extraction
- Step 4: reframe the solution
- Step 5: problem search
- Step 6: problem definition
- Step 7: principle application

There are also different practices within *the application* of biomimicry. Scientists hold varied opinions about how biomimicry should be applied within a design project. Janine Benyus divides biomimicry into two types of applications. She calls the first the "reductive view" (shallow biomimicry) and the second the "holistic view" (deep biomimicry). The reductive view approach examines processes that occur in nature and utilizes them within the design domain by mimicking and imitating certain functions or features with manmade-technology. The reductive view is the most common and traditional kind of biomimicry (Benyus, 1997).

According to Benyus (1997), the reductive view itself can be further broken down into three different applications. The first approach requires studying particular species in nature, and attempting to recreate materials or cells from these species. This process is very complex, and is usually done by scientists at a high-end lab. For example, Richard Taylor, a physicist at the University of Oregon, has been using this biomimetic approach to develop a practice that will restore eye-sight to blind people. He is using flowers as his model. He currently uses a tiny, nano-sized device with electrodes that are shaped like flower petals, and topped with tiny photodiodes. The function of these photodiodes is to collect incoming light. The electrode will pick up these light-based signals and relay them to the eye's neurons.

Once the signals reach the neurons successfully, they will be processed as visual images (Taylor, 2011). These nano-flowers could be placed in a patient's eye with a minor surgical procedure. This idea is still being developed and is expected to be tested on patients over the next 10 years.

The second approach of the reductive view is observing nature and imitating certain of its functions. For example, American design-firm IDEO designed a self-sealing water bottle for cyclists, with a valve that can open, release water, and close with one easy movement. These self-sealing valves were inspired by the tricuspid heart valve, which releases water when constricted or squeezed.

The third approach of the reductive view looks to nature for aesthetic inspiration. It imitates form, shape, and color, with the goal of making products more aesthetically attractive. In these cases, it is evident to most consumers that biomimicry has been used in the product design, whereas in the first two approaches, the aspect of biomimicry used is not always apparent to consumers. The first two approaches are more concerned with applying biomimicry at a functional rather than aesthetic level.

El-Zeiny (2012) has a different view towards this approach. She states that when designers reference nature as their design inspiration, using forms, patterns, or colors from nature to enhance the aesthetic quality of their products, it can not really be called biomimicry. El-Zeiny cites the Spiral Shell House, designed by Senosioan Arquetectos, as an example. Although it looks exactly like a shell, with a lot of detailed patterns and shapes that recall the natural world, this beautiful piece of architecture has no function whatsoever. It is not mimicking nature in a substantive way. J. Vincent (2005) supports the same idea by saying "biomimetics has to have some biology in it." Therefore, it is debated amongst certain scientists and designers, whether this third approach should be considered biomimicry or not. Scientists who are against labeling this third approach as genuine biomimicry believe that a good bio-design is not simply a design that can be rooted back to nature; a good bio-design shares the same level of excellence, perfection and brilliance that is found in nature, a perfect combination of form and function.

The other major approach to biomimicry that Benyus (1997) points to is the "holistic view" (deep biomimicry). The holistic view supports the ideals of sustainability. In his dissertation titled "Holistic Biomimicry: A Biologically Inspired Approach to Environmental Engineering", John Reap defines the holistic approach as one that utilizes biomimicry to develop sustainable products that do not inflict any damage on the environment during production, usage, or disposal. The need for a holistic approach was acknowledged after a 2005 study was published that compared the sustainability of products with bio-

inspired functions to the sustainability of non-bio-inspired products. The results showed that only 1 in 3 bio-inspired products actually have a lesser environmental impact than the non-bio-inspired products (Reap 2009).

But the holistic and reductive views are not opposites. There are gradations between the two. If the holistic and reductive views were placed on a spectrum, the outcome would be three different levels of biomimicry (Boks and Volstad 2012) which are as follows:

The first level is *mimicking natural form or function*, which stands at the reductive view level, and does just what it says – it mimics the forms that occur in nature. This approach is useful in solving specific problems by adapting different functions and forms from nature and imitating them directly. For example, as stated in Boks and Volstad (2012), Dr. Claire Rind of Newcastle University was inspired by how millions of grasshoppers would fly over open plains in Africa without colliding into one another. Dr. Rind spent years studying grasshopper brain neurons, and took her research to the Sweedish car corporation, Volvo. She worked with Volvo to re-apply this anti-collision concept to their cars by developing a feature that can detect pedestrians on the road and warn the driver, or even activate the brakes if the driver does not respond in time. Reap (2009) asserts that because biomimicry is an effort to imitate life, and life has proven to be sustainable, it is easy to believe that a biomimetic product will automatically be less ecologically damaging (more sustainable) than non-biomimetic products. However, test results show that reductive biomimetic products cannot be regarded as more sustainable than the norm (Reap 2009).

The second level is *mimicking a natural process*, an approach which brings designers a step closer to holistic biomimicry. The processes that occur in nature do not, inherently, harm nature in any way and, as a result, the mimicry that takes place is safe and harmless. For example, the process under which an owl forms its feathers occurs at body temperature and is free of any toxin production or high pressures. It occurs through natural, non-harmful chemistry. So any attempt to imitate such a process would also necessarily be non-toxic and thus non-harmful to the environment (Boks and Volstad 2012).

The third level is considered to be true holistic biomimicry, and consists of *mimicking natural ecosystems*. This approach requires the designer to be conscientious of the whole life cycle of the product, starting from material selection to the creation of a re-usable, environmentally-friendly product at disposal. Belletire (2005) considers the holistic view is one that imitates the ability of the natural environment to sustain itself over extended cycles of creation and destruction without harming

itself or its surroundings. This comprehensive, holistic view is mainly approached by eco-designers and ecologists. Followers of this approach believe that biomimicry can only reach its full potential through a holistic approach, giving the designers the whole package – great and sustainable innovative ideas.

2.3 Biomimicry and Innovation

Nature stands as a living testament that natural diversity breeds innovation. This desire for innovation in the marketplace has caused the term "diversity" to become a key word in many companies over the past few decades (Ternaux 2012). Johansson (2006) agrees with this concept, and in his book *Medici Effect*, he argues that the more diverse your team is, in any working environment, the more innovative their ideas will be. He believes that the most progressive and ground-breaking ideas result from collaboration between people of different cultures and ethnicities, different genders, different religious and political beliefs, different economic and educational backgrounds, etc. He uses a metaphor to explain his theory, which he calls "the Medici Effect". He shares this great example in his book explaining his concept:

> A certain café in a port, on an island, in the middle of the Atlantic Ocean, Peter's Café, is just the right place where all this happens. With people travelling from all across the world and wanting a little rest, it has become a cultural crossroad where all kinds of people meet up, share, discuss and debate different ideas and views. Being exposed to new views and ideas which you are against or not familiar with, opens new doors to things you could experiment with and think about, in addition to all the ideas and ideologies you believe in (Johansson 2006).

The term "Medici Effect" is a reference to the famous Medici family of Florence. The Medicis were a wealthy and powerful family of bankers who had a profound influence on the development of Florence by bringing people from all disciplines to work in the city: artists, poets, builders, and of course bankers, among many others. This allowed them to create a very diverse work force within the community, where everyone derived inspiration from each other and the society developed rapidly. A rich culture of art, politics, architecture, and philosophy emerged from Florence, and the world admired and emulated the great city's innovative and progressive civilization (Johansson 2006).

If we were to apply Johansson's "Medici Effect" to contemporary culture, we achieve the same results. Consider, for instance, a chef who uses 5 different ingredients in 5 different dishes; his possibilities would be limited to 25 different combinations. But what if this chef took things a step further and combined the ingredients of the 5 different dishes together, mixing and matching spices and sauces in non-traditional ways? He would then have the potential to create 3,125 different dishes. That is exactly the kind of thinking world-renowned Chef Marcus Samuelson from Sweeden employs. Following this concept, his dishes cross bridges between sweet and bitter flavors, Eastern and Western spices. The result is a unique, world-famous cuisine (Samuelson 2012).

If we were to apply this sort of methodology to industrial design, and cross bridges between technology and nature, our possibilities would be limitless. With millions of known species in nature, and probably thousands if not millions of species that have not yet been identified, there is a wealth of diversity available to inspire and inform designers on any number of projects.

Johansson (2006) developed 7 truths that lead to new innovative ideas:

Truth #1 – New ideas are combinations of existing ideas.

Truth #2 – Not all combinations are created equal, divergent combinations are powerful.

Tip: Find inspiration in fields and cultures other than your own.

Truth #3 – More ideas lead to better ideas.

Truth #4 – Diverse teams generate more ideas.

Truth #5 – Innovation is a creative idea that has been executed.

Truth #6 – Innovation involves learning by trying.

Tip: Allow for failure & recover quickly, failure is the price of innovation.

Truth #7 – Inclusive cultures welcome and invite ideas and opinions.

Truth #8 – Associative barriers prevent us from making overnight connections.

By looking at the chart below (Nike, 2012), and considering the unique combinations that would arise by connecting the visual ideas and personality traits in unexpected ways, one can see firsthand the potential for innovation that such a practice breeds. This chart was used in Nike's 2012 Diversity & Innovation workshop for its employees. It is a group exercise, giving each group random things and asking them to mix the given things together and come up with something unique and innovative, and it is just astonishing what results a rose.

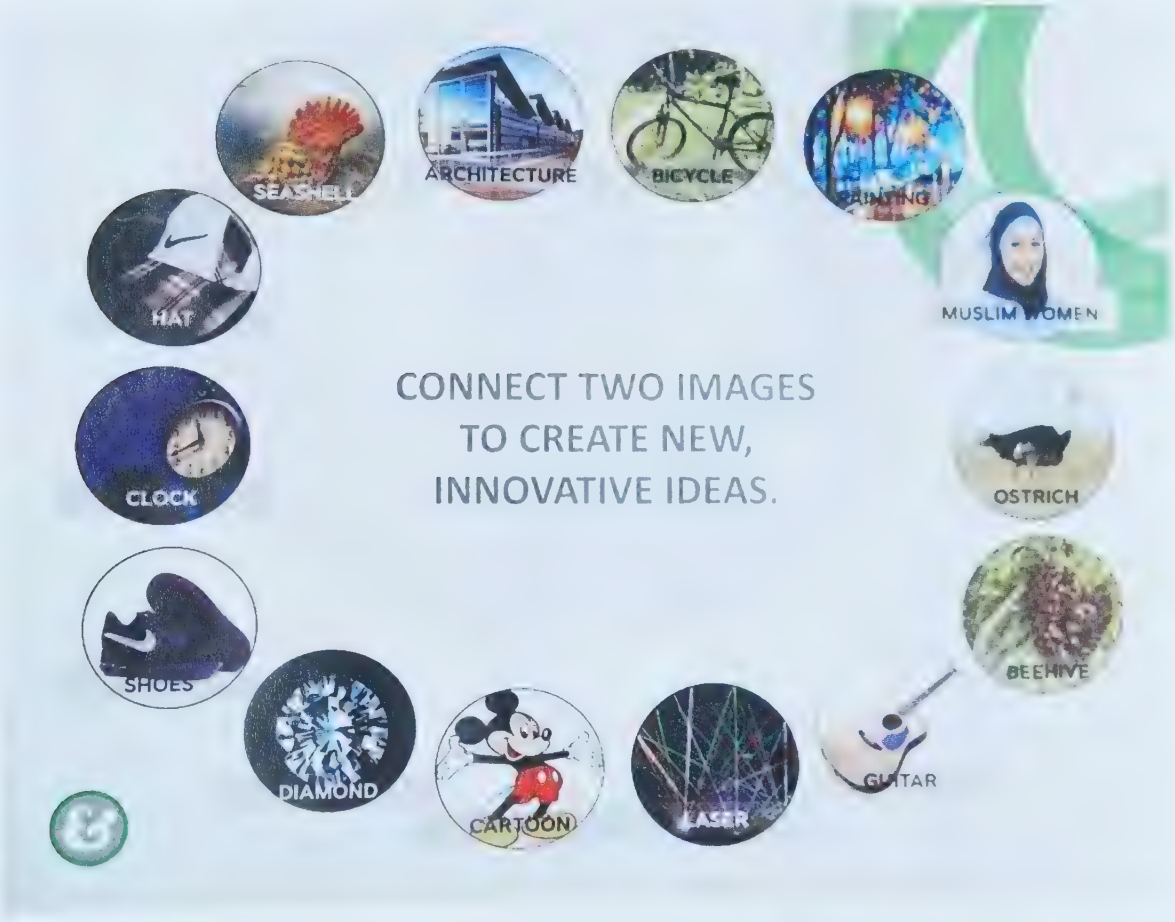

Figure 1 – One of the handouts provided during the workshop. *Source: Nike Inc.*

Experts from Nike strongly believe in this paradigm and theory of how innovation is a result of such diversity. The following is a look at how diverse a team can be, looking at different aspects on different levels, which shape each individual.

Figure 2 - Innovation & Diversity Wheel. *Source: Nike Inc.*

Papanek (1971) viewed biology and its related fields as a potential goldmine for designers seeking new and creative innovative approaches to design. He suggested that designers should maintain and nurture an interest in ecology and ethology to better understand how different eco-systems function, and how different species are able to master the art of survival. According to Papanek, avoiding nature just isn't an option when your goal is innovation. There is too much to admire in the natural world, from the way human beings develop relationships to the way chameleons change color and blend with their surroundings when danger is near. Nature contains countless innovations that we have as yet failed to

mimic. Papanek introduces the idea of it being the duty of humanity to preserve the excellent models we discover in nature, many of which are currently at high risk of extinction due to humanity's careless and selfish treatment of the earth. Every time another species becomes endangered, we have lost another potential answer or solution to a serious problem (Papanek, 1971).

Papanek also voices concern that people may employ biomimicry without good reason. If designers, artists or ecologists get carried away by the concept of mimicking nature and do so recklessly, the results could be counter-productive. Failing to evaluate properly what is necessary and useful, when working on a design project, produces unnecessary waste. While it may seem like imitating nature will produce good results, when one truly steps back and assesses the process, it is often evident that the result of blind imitation is counter-intuitive to nature.

That said, mankind has achieved many great innovations by carefully studying nature's innovations in nature, such as great drag reduction, dry adhesion, self-cleaning materials, energy conservation, among many others (Quinn & Gaughran, 2010). It is astonishing what wonders small creatures can teach us. The car company Mercedes came up with an amazing concept called the Boxfish, with superior aero-dynamics that were inspired by the swimming patterns of the Boxfish and their shape and form. Gecko legs inspired the invention of dry adhesive. The legs of Geckos are covered with billions of tiny hairs that are able to grip on to any surface (Ben-Ari, 2002). The more hair you have and the smaller the hair is, the stronger the adhesion will be (McDonagh 2009). In addition, Gecko feet have taught scientists even more about how products stick to surfaces, and have informed them about how snowflakes stick to surfaces or how spiders acrobat around their webs, also known as the Van der Waals force (Quinn & Gaughran, 2010).

Jay Herman is another great example of an innovator who was inspired by nature. As a beach lover, he realized that fragile seaweed resisted destruction from the violent tide by swirling in the same direction as the ocean's flow, similar to the circular movement water makes swirling down a drain. His curiosity and interest led to a scientific investigation of fluid and air dynamics, in which he learned that, "All movement, or turbulence, in the universe is designed around this whirlpool shape. Humans try to make things in straight lines, and then use a lot of energy to overcome turbulence. But nature exploits the turbulence." Herman now runs the engineering research and product design firm PAX Scientific, which has developed a series of innovations in the function of water systems based on Herman's concept of flow (Ghahremani 2012).

As more amazing research falls into the hands of designers, more innovations are being developed. Learning from nature fosters a lot of hope for the future. For instance, researchers have been able to project the high-frequency sounds that dolphins make and develop them into high-definition images from their sonar feedback. This could have endless benefits, the biggest being for visually-impaired people by providing them the means to navigate through a similar sonar system. Bats tend to navigate the same way, by being directed by the echo's they hear from he sounds they make (Pailhas, Capus and Brown 2012).

Although many biomimicry projects in the past have succeeded in identifying important design problems and solving them through nature, it is unfortunate to note that many of these great ideas do not move beyond the concept phase. They pass all the necessary testing, but they never get launched into the market because it is still difficult to entice big corporations to take a serious interest in biomimicry (Ghahremani 2012). The reason for this is that utilizing new biomimetic approaches requires a lot of time and a lot of advance research, but that is a price you must pay and risk you must be willing to take in order to innovate (Boks and Volstad 2012).

2.4 Useful Applications of Biomimicry

> Biomimicry is an invaluable tool for creating more sustainable products and practices, which is especially important as we face the need to adjust and respond to major environmental crises, such as climate change. It is crucial that we observe and learn to mimic nature's ability to create adaptable habitats (Priesnitz 2012).

American ecologist Herman Daly says that while human population growth has caused our living conditions to change drastically, our actions and strategies have stayed the same. Therefore, we are continuing to put fatal stress on our environment. We should be changing our habits and practices to remain "in sync" with the changes in our living conditions (Priesnitz 2012). There is no better way to achieve this feat than through the application of biomimicry. By emulating nature's patterns, we will be able to create new ways of living that do not damage the environment. Biomimicry can be used and applied in almost every field. Most traditionally, it has been applied in the field of design. For example, material engineers who work in the textile field are always studying how different materials are made or function in nature, such as spider silks (Eadie & Ghosh, 2011). Each kind of spider uses different amounts of proteins to produce different kinds of webs (Hayashi, 2001). Recently, interest in spider silks has been

explosive, as they combine delicacy and strength almost flawlessly (Vollrath and Knight 2001). Even more interesting is that over 34,000 species of spiders have been identified, and almost all of them possess the capability to spin a variety of silks that possess varied mechanical properties (Gatesy, et al. 2001). This knowledge could revolutionize the world of textile production.

Boundless inspiration for automotive design can be found in the habits of air and sea animals. The shape of an animal's body (aerodynamics) and the quality of its skin (skin friction drag) have a tremendous effect on the capacity for efficient movement (Cengel and Cimbala 2010). For instance, the movement of sea creatures is influenced by three major factors: skin friction drag (the skin of the fish), form drag (the shape of the fish), and wave drag (the pressure and motion of the water surrounding the fish) (Wang, 2004). For instance, sharks are able to maneuver quickly and efficiently under water because their skin is covered in tiny tooth-like scales, known as "denticles" (Bushnell & Moore, 1991). These denticles allow water to channel through the gaps in between them, causing the water to flow much faster over the skin and reducing skin friction drag (Lang et al, 2008). The thinner the denticles, the lower the drag force, and the faster the shark can swim (Bechert et al, 2000). Shark skin has not only inspired underwater products and swim gear, but has also inspired the material used for external aircraft casing and pipelines that need to transport large volumes of liquid quickly and efficiently (Roberts et at. 2003).

Birds have provided great inspiration in the automotive industry. An excellent example is the Toucan. The Toucan's beak comprises one third of its body, yet it only makes up 5% of its entire mass. This is an excellent resource to study when developing light-weight but strong materials that are able to handle extreme impact (Wheels.ca, 2009).

The promise of biomimicry is not simply limited to greener living and better design. The knowledge we glean from nature can help us to design better policies and products that will improve our quality of life on all levels (Priesnitz, 2012). For example, Rachel Page and Michael Ryan of the University of Texas at Austin applied concepts of biomimicry in the field of education, they researched the role of social learning and cultural transmission in bat foraging. The results showed that the more time young bats spent observing older, more experienced bats, the better equipped they were to find abundant and high quality food (Page & Ryan, 2006). Imagine applying that concept to the education system, where students are not merely told information, but were provided more opportunities to observe the application of important skills, and practice what they see.

Looking at Biomimicry from yet another perspective, it could inspire solutions to many of our current problems with developing a just method of governing society. According to Cornell University biologist Thomas Seeley, we could learn a lot from observing honeybees, and how they collaborate when choosing a new hive to inhabit. The decision-making process of honeybees is similar to the process that neurons undergo in primate brains when a primate makes a decision. In both instances, there is not a single bee or neuron that is capable of achieving an overview of the general situation. Instead, independent bees or neurons provide different pieces of information. The group then takes all this individualized information and, without granting any one piece precedence over another, fuses it together to make an optimal decision. This allows different types of information to combine and grow into new, superior knowledge. "Consistencies like these suggest that there are general principles of organization for building groups far smarter than the smartest individuals in them" (Seeley, 2010). The decision-making system of bees is currently being used as a model for disaster relief by researchers at the University of Illinois at Urbana Champaign.

Bio-inspired products are ground-breaking, innovative and sustainable. Biomimicry provides guidance, while simultaneously granting us the space, knowledge, and opportunity to break boundaries and achieve revolutionary progress. Biomimicry is not only the future for better design, but for a better society and improved quality of life for all (El-Zeiny, 2012).

Design Approach

Last summer I had the honor of participating in a 12-week internship program at Nike's World Headquarters in Beaverton, Oregon. I knew this experience would be inspiring, but nothing could have prepared me for the unexpected directions in which this internship would lead me. My time at Nike opened my mind to innovative thinking and revolutionized my approach to design. I met numerous illustrious designers, and was able to interview several about their work at the company, and talk to them about how innovation has shaped their careers. In addition, I attended numerous lectures given by Nike's most noteworthy leaders and creative minds, an experience which not only introduced me to new concepts, but inspired my thesis on biomimicry and innovation. In this chapter, I will introduce the brilliant people I encountered and discuss their ideas, relate my most inspiring learning experiences, and explain how all of this has influenced my own work. I will place a special focus on how these experiences have influenced my designing thinking and overall process and approach towards design problems, and how they have ultimately led me to my thesis topic: innovation, inspiration, and biomimicry.

Figure 3 - Nike Design Interns 2012

3.1 Lessons from Nike Inc.

Week 1 – What Made Nike What It Is Today?

My first day at Nike was packed with excitement and activities. The events were designed to familiarize the new interns with the campus and introduce us to the people with whom we'd be spending the next 12 weeks. The most exciting point of the day was a series of talks given by the Nike leaders we all so admire. The first speaker was a great surprise to everyone: Mark Parker, CEO of Nike, Inc. The fact that someone as busy as Mark Parker had found the time to talk to a group of motivated young interns was, in itself, inspiring. Listening to him share his own story was powerful. He didn't stand in front of the crowd and boast. He discussed the frustrations and obstacles he faced when he first joined Nike, talked about the company's failures as well as successes, and shared what he is learned from his mistakes. In addition, he gave us tips to carry with us on whatever career path we choose to follow, be it at Nike or anywhere else. I found the following four pieces of advice particularly beneficial:

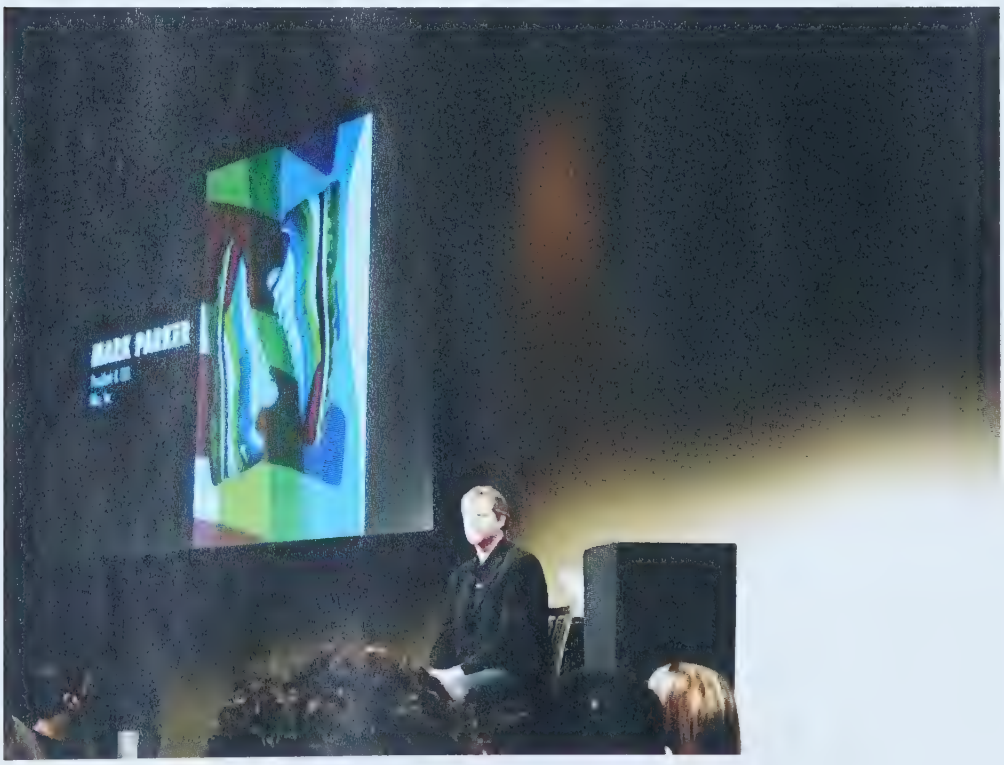

Figure 4 - Mark Parker, CEO of Nike Inc.

1- **Listen**. Always give others the opportunity to express their ideas, and respect what they have to share, even when you disagree.

2- **Speak up**. Don't be afraid to express your ideas and bring what you have to the table. Titles and higher positions are meaningless in the face of great ideas. He said, and I quote, "Nike was not built by bowing down to titles."

3- **Focus**! "Stick to your core, commit to your work." In other words, do what you are most passionate about, and do whatever you can to excel.

4- **Team work**. What you can accomplish as a team you can't even dream of achieving by yourself.

He also discussed some of Nike's core principles and their influence within the company as well as how they extend into the world. Parker's talk brought to life Nike's motto "Believing in Human Potential." He emphasized the importance that Nike places on nurturing the potential of employees and athletes alike, which is an inspiring and progressive concept. He explained how one of the company's favorite mottos, "Achieving the impossible and unseen," expressed Nike's commitment to bringing innovation and inspiration to athletes world-wide. But Parker's main focus was the importance of team work at Nike. I found that this concept did not just come up in talks. Throughout my time at Nike, the importance of collaboration was evident in every task and challenge I faced. And, it became increasingly clear how the positive mindset of a single team made it much easier to develop innovative ideas. I learned how choosing the right team of designers and maintaining that team's positive energy and sense of unity is crucial to every design project, including my own.

The second speaker was Rick Shannon, Director of the Department of Nike Archives, who spoke to us about the history and culture of Nike. I learned several very interesting lessons about how to think outside the box to create an environment that will lead to innovative design, and how to tap into the boundless potential of collaboration. Shannon spoke about how true innovators must constantly challenge themselves and everyone around them, take risks, and, when necessary, to defy the majority. He shared the inspiring story of Bill Bowerman and Phil Knight, the co-founders of Nike. Bowerman was Knight's track and field coach at the University of Oregon for years before they teamed up and combined their different areas of expertise to make Nike the globally-successful company it is today. Knight was an athlete, not a designer, but he let go of his anxiety that he didn't know enough about

sneakers to be a good designer. Instead, he added his insight as an athlete to Bowerman's experience and turned it into something even greater. Listening to these stories taught me how to trust my gut and tap into the courage it takes to explore new concept. What it all comes down to is performance, innovation, teamwork, commitment, and authenticity. These are qualities that will define my own design philosophy from here onward, and inform how I approach my own work.

These talks made me reassess the potential that lies in innovative collaboration with nature *through* biomimicry. Instead of letting my lack of experience make me feel intimidated when I face the vast mysteries of nature, I've learned how to embrace that sense of the undiscovered as a force of inspiration.

Week 2 – A Designer's Mentality

During the second week, several top designers at Nike gave presentations that provided a real glimpse inside the mind of a successful designer. The main talk was given by Howard Lichter, Global Director for Creative Outreach at Nike.

Howard Lichter has been with Nike for 16 years, so he had a lot of stories and advice to share. The first point he made was that a designer cannot be stationary. He explained how he has had to be consistently flexible and ready to step into a variety of roles. For example, he had never imagined himself in Asia, but he ended up playing a major role in setting up the Nike Design Studio in Japan.

Lichter's talk was highly motivating. He fired up our energy levels and he shared valuable insights that most designers only gain from experience. Several important points he covered are below:

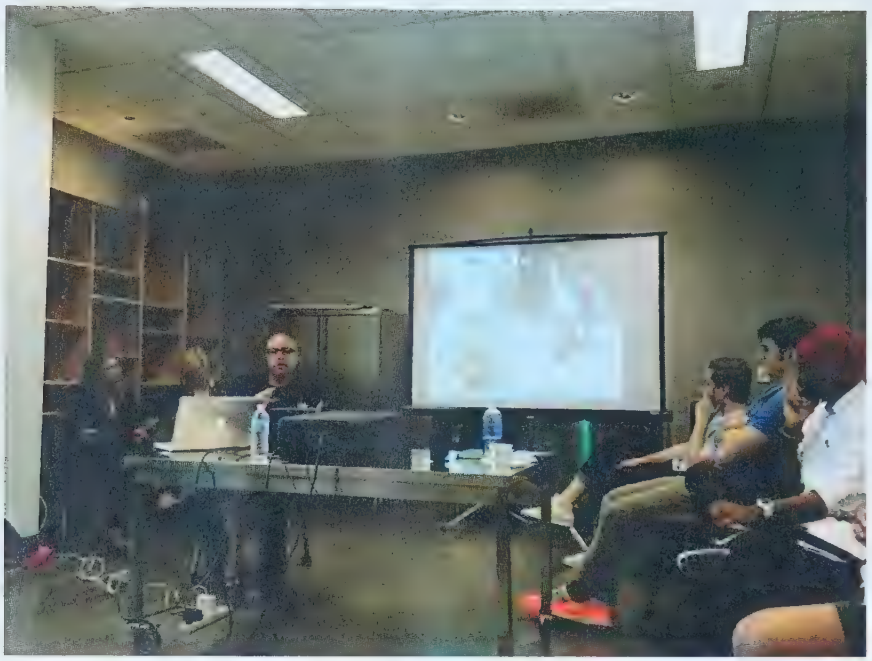

Figure 5 - Figure 5 - Howard Lichter, Global Director, Creative Outreach

1. You say obsessed like it is a bad thing!
    - Lichter's formula for success is what he calls the 70/20/10 rule: 70% passion, 20% obsession, and 10% talent.
2. They know when you're faking it.
    - Whether you're dealing with an athlete, client, manager, or yourself, understand that person deeply. The more you know, the better you will design.
    - Authenticity is everything.
3. Insights:
    - You can't put a price tag on the insights gained from working with athletes. The opportunity to connect with players on a personal level is invaluable. As Phil Knight says, "Listen to the voice of the athlete."

4. Innovate or die trying.
    - Don't do "new & different," do "new & better."
    - Solve a problem, enhance an experience.
5. 5. There is no "I" in "Team."
    - Working alone is like driving down a one-way street: no options, but collaborating as a team and sharing ideas turns a project into a journey with limitless detours complete change of direction. That's when innovation shows up!
    - Network with as many people as you can. Networking = Survival.
6. Sweat the details.
    - Attract interest, engage attention, and maintain connection.
    - Own the process and finish strong.
7. Tell great stories.
    - Be a great presenter. Don't just talk. Connect.
8. Make design a journey. Savor the experience.

Lichter's presentation was enriching and beneficial. Often, designers will talk about process and try to convince their audience to embrace a particular approach or attitude to design, without taking the time to connect with them. But Lichter was different. He provided us with encouragement and motivation, and talked about how refusing to accept limitations frees the designer to be truly innovative. It was some of the most valuable design advice I've received. Bringing these principles to my own work will motivate me to continue raising the bar and produce outstanding designs.

Week 3 – Thomas Walker, Bringing Innovation to Apparel Design

During my third week at Nike, I had the opportunity to meet with Thomas Walker, Design Director for Apparel in Nike Running, to conduct my first of several interviews. I viewed this as a chance to discover

how Walker, an extremely successful designer, thinks, and more specifically, how he thinks about innovation. When I look at great design work, I'm always curious to understand what was happening in the designer's mind when he or she created that product or logo. What inspired that designer to think in that particular way? In this interview, and all the interviews I conducted during my internship, I tried to delve deeper. I wanted to discover more than the designer's opinion on certain topics; I wanted to know how he or she thinks during the design process and gain a better grasp on what constitutes true innovation.

My first question for Thomas Walker was what innovation means to Nike today. He said that, from the perspective of an apparel designer, there are two parts to innovation: performance and style. Innovation in performance is not only one of Nike's founding principles, but also its competitive edge. Nike is known for defying consumers' beliefs and creating products that were previously thought impossible. As the company has matured, he explained, it has started to connect with consumers on an emotional level, and that's where style comes in. According to Walker, style is much more than seasonal trends. Style is the arena in which Nike exerts a global influence and leaves its mark on all corners of the world.

So how exactly, I wanted to know, did innovation mesh with style? Walker answered by explaining one of Nike's current projects—making jerseys out of recycled plastic bottles. Talk about innovative! He continued to discuss the need for sports apparel to adapt to the body. For athletes, clothing should feel like a second skin and should assist performance. So Nike has done a lot of research based on scanning athletes' bodies to get an absolutely perfect fit. But enhanced performance isn't the end goal. Innovation steps in when Nike strives to create products that have a dual function: superior performance and positive psychological effects. Athletes feel better equipped to meet challenges when wearing custom-fit apparel. Walker spoke about how many athletes like Nike's tight-fitted jerseys because they feel locked-in and secure, and are more conscious of their muscle mass. But you have to consider that the tight fit is less comfortable in hot weather than cool, which raises the question: how can Nike designers use innovative thinking to create a material that can adapt to various climates, so it is as successful in Moscow as it is in Brazil? The answer is a "smart material," and Nike developed one a few years ago called *SphereReact*. It has little pods that open up when an athlete sweats. Nike is still working with modifications for *SphereReact* because innovation does not stop with success; innovation sees no end to improvement.

We also talked about how Walker gains insights into the market. He says that the first step is understanding the consumer. For example, he and his team were recently in LA working with five 20-year-old women. For two days they observed them in their daily routines, making note of their clothing, the colors they preferred, the sneakers they wore to run and the shoes they wore to go out at night. They talked about the social world they inhabited and its demands. Once the team had a sense of the women's lifestyles, they called in a stylist who gave each woman a makeover based on the teams' observations. Recording the women's reactions through each stage of the makeover helped the team develop a sense of how they make fashion decisions. The other essential insight for any designer to possess, Walker said, is understanding trends. The team travels to major fashion centers like London, New York, and Tokyo to see what's hot and what other companies are doing. From there, Nike takes what is popular in radical new directions.

Looking to the future, Walker sees innovation as the incorporation of performance data into products. We live in an age where we have access to more information than ever before, and everyone wants to know what is going on inside their bodies. Walker thinks this desire for knowledge can be embodied in apparel. What if your sneakers could provide feedback on your performance? What if a coach watching his football team play could see through the uniforms and see when muscles are starting to fatigue, and call in a substitute before the athlete gets injured? Or what if there were a material that could measure dehydration? The possibilities for future of innovation are endless.

The benefits that arose from the chance to interact with people whose ideas have such a tremendous impact on the industry and its future are substantial. I have gained invaluable insights and knowledge of the industry from these interviews, but the most significant lessons I learned from this first interview were unexpected. I learned to feed my curiosity and ask plenty of questions, and to connect with the right people, people who will challenge me and help me to grow in new directions. This has had a major influence on my design approach overall, and I expect that influence to continue as I move forward.

Week 4 – Jason Mayden on Innovation

At the end of my first month at Nike, I had the opportunity to interview Jason Mayden, the Director of Innovation-Digital Sport. We started out by discussing Nike's role in the future of innovative design. Mayden's first point was that we are moving into a second industrial revolution, but most designers have not realized it yet. During the first industrial revolution, innovation was expressed through mass

marketing, which created the desire for products that were cheaply-made and looked great. Fast forward to where we are today. We live in a data-centric economy, where everything we do can be measured and quantified. That means that innovation does not lie in the hands of engineers; it is going to be designers who transform that data into services or products. In order to think innovatively, designers must constantly consider the whole spectrum from end to end, from product conception to the physical object to consumer benefits.

One of the most exciting innovative ideas that Mayden discussed was predictive service, or understanding the consumers' needs and desires before the consumer even knows they exist. In the past, the design process ended with the physical product, the shoe, and all roads led to that shoe: communication strategy, design strategy, and everything else. Now, rather than having the product waiting at the end, it is in the middle of the road. And, many more roads branch out from that shoe because it now enables a set of services. For example, if you buy a Nike+ basketball sneaker, not only will it make you feel good, it will actually improve your performance. It will record your past data so you'll be able to anticipate your next move before you even make it. It will be able to tell you how many miles you covered on yesterday's run, and use that data to ascertain the ideal distance you should cover cycling today. Your sneakers will alert you if you aren't drinking enough water. They will perceive muscle fatigue. According to Mayden, innovative design lies in the designer's ability to stay several steps ahead of the consumers and to create consumer demand along with the products. Nike is not going to ask people what they want. Nike is going to look at the data and anticipate what the people want before they are aware of it. Henry Ford said it best: "If I asked the people what they wanted, they would say a faster horse, not a car." And as designers, we offer them whats best, and the car becomes the better alternative.

Then we talked about the future of innovation, and if it lies in the digital or the physical world, he answered that it lies in the merging of the two realms. Nobody's lining up to download the Nike fuel band app; they're lining up to buy a new shoe or cutting-edge device. People still want physical products, so innovation demands combining the physical with the digital. People want to accomplish more and carry less. Nike's future innovations will strive to combine useful digital features into unlikely products. When I asked Mayden how a designer begins to understand what people find useful, he advised me to keep asking questions. Listen to the answers, let them resonate. Eventually everything will gel, you will do something really cool, and it will take off.

Week 5 – The Story about Story

I attended a fantastic workshop about the art of storytelling led by Dennie Wendt, Senior Copywriter at Nike, called "The Story about Story." Wendt discussed the importance of telling a good story in your design, and shared different storytelling techniques. Aspiring designers often forget that before actually launching a design project, designers are often required to present their proposals to colleagues or clients. Submitting high-quality work is just one part of the process; the second part relies heavily on storytelling abilities. The talk focused on the power of story within design, and how that translates into a successful presentation.

Wendt introduced the concept of power in story with a Ken Kessey quote: "To hell with the facts; we need stories." People use narratives to create meaning in all areas of life. Stories help people to understand and connect with the world. So why not think innovatively and bring this concept to our designs? Stories are an effective way for a designer to make personal connections with his or her audience, and to communicate the reason and intent behind the design itself. This practice does not disregard facts; it simply places them as a secondary step. With the story in the spotlight, the facts are complementary. Metaphorically, the facts are the individual notes that work to make the melody that the audience appreciates, the story or the song.

Figure 6 - Denny Wendt; Senior Copywriter at Nike

But great stories fall flat if they are not told in a compelling manner. Your story needs to be exciting every step of the way. You need to engage the audience and make them care about what comes next. Sequencing matters. For example, if someone has been in a coma and has no idea what happened in the NBA Playoffs, how would you explain what happened? You would probably not start by talking about the first rounds and the players that got injured. You would start with the highlight of the story: who won the championship! Then you would move on to the specifics that led to the big moment.

John Carter, one of Disney's recent films, was written by two of the greatest storytellers of our time, Andrew Stanton and Mark Andrews. Despite great expectations, the film was badly received and lost millions of dollars. The reason why people were disappointed was that they had no clue what the story was about. It had no focus and no real target audience, which left people extremely confused. Therefore, it is crucial to know what your story is about, and who you are addressing.

What I took away from this experience was how to incorporate stories into a design so the design or product itself tells a story. For example, if I designed an innovative soccer shoe, inspired by a particular element in nature, and the shoe reflected its natural source, it would possess a finer quality of detail for consumers to appreciate. Not only would nature serve as a resource for emulating function, but it would also tell a fascinating story.

Week 6 – Nike Design VPs on Innovation

In week 6, I got the opportunity to sit down with three of Nike's Design VP's: John Hoke, Tinker Hatfield, and Andy Caine, and conduct personal interviews. We talked for a long time about what innovation means in the design world today. First, we discussed Nike's design philosophy, and how Nike maintains such a high standard of innovation. Tinker Hatfield explained how Nike's goal is to design products that are functional. Many companies get caught up in aesthetic appeal and forget about utility. But Hatfield said that function has to trump art. And, he emphasized the importance of allowing the product to exhibit the technology that distinguishes it from the rest. He discussed Nike's visible Air sneaker as an example, which has visible external heat counters and additional holes in the material for better ventilation. People like to see what differentiates their product from the rest.

While Hoke piped in to acknowledge the need for function in a product, he didn't think it necessarily trumped aesthetics. He introduced the concept of "beautility," or beautiful utility. While functionality is crucial to good design, according to Hoke, it is only the first step. The world has plenty of ugly function, and it is the designer's responsibility to act as a visual poet and deliver glimpses of beauty to humanity, to show what is possible. So while function should not be forgotten, the line between form and function is blurred. For a design to be truly iconic, it needs to fulfill function and aesthetic demands. A product needs to engage a consumer's attention so that it becomes more than just a product; it needs to be an experience. He created the phrase "complex simplicity" to articulate the idea of using highly-complex materials to create high function that is housed in simple design. The goal is to demand a deeper level of engagement between consumer and product through beauty as well as functionality.

Figure 7 - With Tinker Hatfield, VP of Design at Nike Inc.

Hoke's and Hatfield's visions coincided when they discussed how Nike's approach to product design is rooted in problem-solving. Hoke suggested that there are two ways to look at problems, with laser-sharp focus and broad scope, the way you would take in a landscape. To think innovatively, a designer must be able to transition between these two perspectives with ease. If you use too much laser beam

focus, you are at a risk of missing the larger picture. True innovation is born of deep understanding, which demands clear sight of the bigger picture.

Andy Caine's thoughts on innovation centered around the same concept of dual vision. He named the two elements of Nike's DNA to be the enhancement of an athlete's performance and the partnership between athlete and designer. He pointed to Nike's dedication to working with the human body as a foundation to achieving innovative design. At Nike, the design process revolves around a deep understanding and a deep respect for the human body. Where nature stops, the genius of man begins. Nature has given us incredible systems—skeletal muscular, circulatory, nervous—and athletes challenge those systems but the body has limitations that can be frustrating. The designers at Nike consider it their job to defy those limitations by designing around them, giving consumers and athletes a "super power" to be able to break boundaries.

But these accomplishments are not easy to achieve. I wanted to know how these VPs accomplished such great advances in design. So I asked them what they find inspiring. I was surprised when the first words out of Caine's mouth were, "Don't work too much." At some point, he said, you need to balance input and output, otherwise your creativity will literally dry up. In order to grow your creativity to the next level, you have to absorb as much of the world as you can. Caine does a lot of action sports to learn about calculated risk; how far can you push yourself without getting hurt? He also invests a lot of time in understanding pop culture. He reads magazines, browses the Internet, looks at fashion, and listens to the radio. "You have to be a sponge," he said.

Hatfield echoed Caine's emphasis on curiosity and observation. He talked about the importance of going out into the world and deriving inspiration from new experiences. Like Caine, Hatfield finds participation in sports key in developing innovative sports designs. Inspiration is born of participation, not merely observation. His recent experience watching athletes compete at the US Olympic Track and Field trials made him want to sit down at his drawing table and accomplish the visual equivalent of the physical exploits he had witnessed. But Hatfield finds his hobbies of motorcycle riding, surfing, and mountain-biking equally crucial to the design process. You have to look beyond the world of design to find fresh inspiration. That's what results in innovation.

Our conversation eventually wound its way toward the future of innovation within Nike. Caine summed it up in a single word: "globality." He talked about his experience working with Nike Football, and the need to get and remain globally and culturally connected. For instance, if you are designing a jersey for a

team of working-class football players in Brazil, you have to have a pretty thorough understanding of their culture. If you get it wrong, the team isn't going to like or wear that jersey. As Nike designers look to the future, they see China rising, Russia rising, Brazil rising, as well as growth in Poland, Mexico, and several countries in the Middle East. The world is getting smaller, and Nike strives to be a global brand, one that respects and connects with all cultures. In order to make the most of these unique opportunities, Nike needs to maintain global appeal while taking advantage of regional opportunities. Finding a way to appeal to both regional and global culture will result in a wealth of innovation.

Caine also talked about the explosion of digital media. He talked a lot about how Apple has maintained such a high standard of success. Apple is able to create pivotal moments. For example, five years ago, "apps" didn't exist, but today "app" is a household word. How can Nike be part of these pivotal moments? Hoke's answer is the collision of technology and craft. The future of innovation in Nike is going to incorporate digital computation skills with high aesthetic standards. Designers will act as digital craft-makers. Nike currently has a data-led design strategy which leverages information and converts it into intuition, then transmutes that intuition into emotional connection. He suggests taking statistics from athletes and incorporating that data into a functional feature of a shoe, or body suit, or pair of eyeglass. Designers are thinking about how to make products technically alive. The question isn't how technology will change the way a product is built, but how technology will change the way a product affects the body and its responses. The ability of a product to interact with the body in this way would change the experience of athletes.

Hoke's parting advice to me was to think about my thesis as part of the future of innovation. He said that in pairing biomimicry and innovation, I am challenging the point where nature ends and technology begins. And that is where the future lies.

Hatfield advised me to keep an open and receptive mind. Talk to people from different cultures and backgrounds, and find different ways to bridge the gaps in these interactions. This will teach me how to think innovatively, and access fresh ideas on a regular basis.

Caine's final words were to stay hungry and stay excited. He talked about his own experience, how he played by the rules in college, and that was fine, until one of his teachers told him, "You did exactly what I expected. That's not good." Caine's most important lessons as a designer were how to take risks, how to be bold, how to challenge the status quo and think outside the box. And he told me that, as a designer, I should settle for nothing less than my wildest dreams.

Week 7 – Mark Miner on Inspiration and Design Process

Mark Miner, Senior Footwear Designer in Nike's running department, was a fascinating person to talk with about innovation and design. He spoke eloquently about inspiration and said that most people think that inspiration happens instantly. You feel like you've been shot through with electricity, like you could do something magnificent with that color or shape right in the moment. But Miner believes that inspiration is a process. Sometimes it is instantaneous, but other times the power of a moment lies dormant for months. Designers are like sponges that absorb everything, and sometimes it takes an observation or an image years to show up in the form of inspiration. Inspiration can come from patterns and colors, and also from people. Miner finds some of his deepest inspiration in watching people interact, and said that if you can understand people's psychology, you can understand how to design innovative products that they desire.

He also equates innovation with progress, and said that every design project should be a little more progressive than the last in that it takes the consumer someplace new. In order to design products that chart new terrain, a designer has to have a vision. So when you're brainstorming and one idea stands out as really crazy, don't be afraid to follow it to its end. This might cause you to run into some obstacles and problems, Miner admits, and most people prefer to avoid problems at all costs. But Miner believes that deep down, designers are different in that they seek out problems. Problems give designers direction and goals; once a designer sees a problem, he or she knows to go after it and figure out a solution.

Miner also believes in conscious flow. He thinks every designer should travel with a notebook and a camera. Take pictures, take notes. Even if you don't look at them right away, at some point you'll turn back to those pages and find gems and fresh ideas. He thinks you should note everything, the good and the bad, in order to achieve honesty and purity in design. Ideas are not born perfect, and for a designer to criticize his or her conceptual mind is dangerous. Let your mind be free, Miner said. Let your ideas flow, and you will find inspiration and innovation in the most unlikely places.

Week 8 – Immersion Programs

Every year at Nike, a number of employees take trips to countries in Asia and South America to learn more about the culture and the markets in these developing nations. They strive to gain a richer

understanding of the different styles of craft and skill sets being used abroad, and spend weeks researching and studying different design and craft techniques. When they return to Nike, these teams share their knowledge and inspiration, which results in exciting innovations.

Jesi Small, a Footwear Designer at Nike Action Sports, came in to talk about her recent experiences in Japan. She showed us a collection of items she had brought back with her, and explained what she liked and appreciated in each piece. Whether it was the detail, material, concept, or simply a particular feature she found appealing, Small was able to point out how it has inspired one of her current designs. She also told us about her trip to visit a master weaver, and how witnessing every small step of the process, from the dyeing to the use of different weaving techniques to create nuanced effects, was just mind blowing.

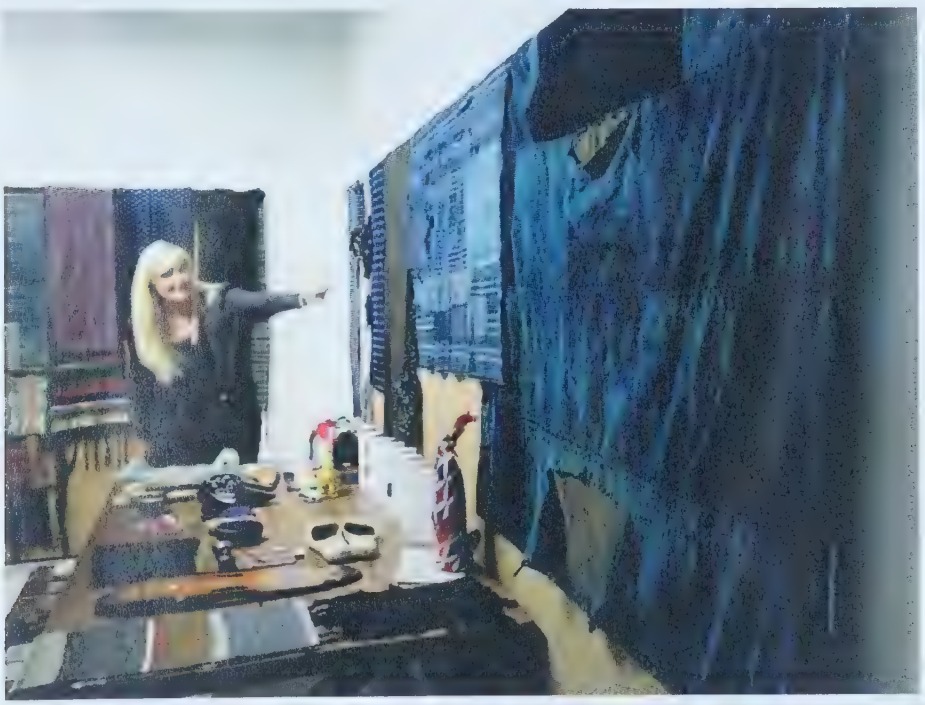

Figure 8 - Japan Collection – Jessi Small

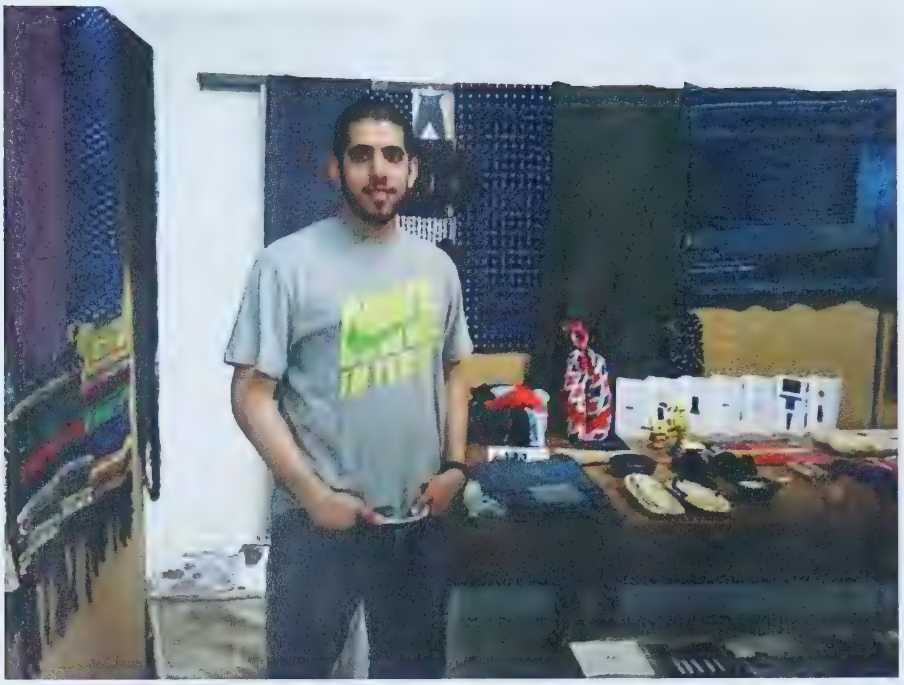

Figure 9 - Japan Collection – me

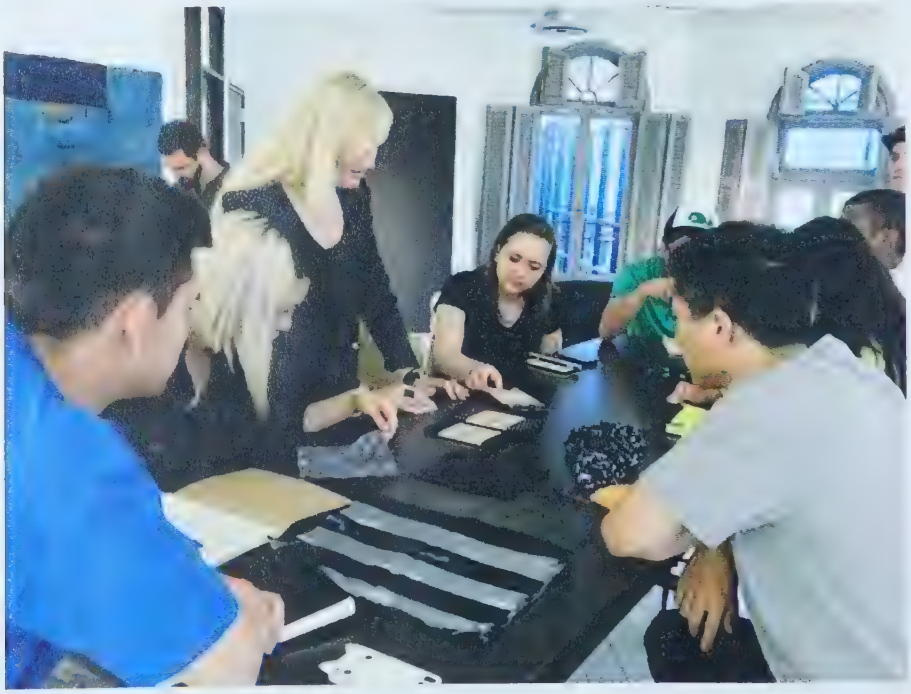

Figure 10 - Jesi Small, showing us the different materials and weaving methods used

Figure 11 - One of the interesting objects brought from Japan

Erick Goto, Graphic Designer at Nike Basketball, also shared stories from his travels. He wrote a book of reflections on the two months he spent in Japan, called *Breaking Habits*. He spoke extensively about what distinguishes trends in Japan from those in the United States, how authenticity asserts itself in Japan, and different methods of storytelling through products. He really showed how travel allows you to not only understand a culture through its products, but also through getting to know its people.

Golnaz Armin, Material Designer at Global Football, also created a book chronicling her two-month trip to Amsterdam, titled *Hand In Hand: Traditional Dutch Design*. The excerpt below beautifully articulates the depth of her communion with Dutch culture:

> Many of the insights from this trip came about through conversation and observation. There are some things you just can't experience and research through Google. The power of the Immersion Program is that you can observe, first hand, the nuance and poetry of a culture. I experienced a multitude of different collaborative and creative environments, ranging from traditional manufacturing at Leerdam Glass to experimental

> digital design at Pinar & Viola. This journey inspired me to explore different types of collaboration and creative processes...Perhaps the biggest and most relevant realization from my deep dive into Dutch Design is that color and materials can be experimental and thought-provoking. By reaching to the past and to tradition, one can give context and meaning to every element of design in the present. (Armin, 38)

It was interesting and inspiring to see how much Nike invests in enriching its designers by providing them with such unique experiences and opportunities. It soon became clear to me that a major component of being part of Nike Design is the relentless search for fresh inspiration through first-hand experience. Nike designers are trained to keep their eyes open, to research, and to invest their whole selves in every experience. This is why the company continues to grow and remains one of the leading innovators in sports apparel today.

This experience made me eager to plan my own trips, and to expose myself to unfamiliar ideas and foreign cultures. As a result, I took my own inspirational trip and visited three Middle Eastern countries, which I discuss more thoroughly in the next segment of this chapter. I brought back inspiring products, rare materials, new techniques, fascinating stories and unique thoughts and observations. And I experienced for myself how such exploration leads to innovation.

Week 9 – Nike Innovation Kitchen: Wilson Smith, Michael Shea, and Toby Hatfield

A special place at Nike is the Innovation Kitchen, where some of the company's top innovative minds work together to develop ideas for new products. I had the opportunity to spend some time in the kitchen and talk to three of these renowned innovators, Wilson Smith (Footwear Design Director), Michael Shea (Global Director, Communication and Storytelling, Design Center of Excellence), and Toby Hatfield (Kitchen Innovation Director).

We talked a lot about how innovation informs Nike's design philosophy. Hatfield named the most crucial element in the design process to be listening to the athletes. Many companies design a product first, then ask the consumers if they like it. Nike works differently. Nike spends a lot of time talking to athletes and using that information to design products that speak to their needs. The authenticity of Nike products does not live in the "Swoosh" design; it lives in the presence of the athletes being evident in

every product. Just look at our tags, Hatfield urged. They usually read, "Designed and built for the exact specifications of athletes."

Wilson agreed with that notion. He spoke of Nike products possessing three things: performance, beauty, and soul. Performance means they work for the sport, beauty is the aesthetics, and the soul he speaks of is insight that other products do not have. Nike products speak specifically to the athlete because Nike understands that when designing a product, the athlete comes first. Without the athlete, there are no grounds for innovation.

Shea pointed to Nike's refined designed ethos. Nike uses very simple, intuitive and beautiful forms that make innovation visible. He used the Nike "Flyknit" sneaker as an example, which is a sneaker made completely out of one thread, which would eliminate having any waste when producing it. In addition to being attractive, it is intuitively very compelling because when you pick it up, it weighs next to nothing. The theme of listening to the athletes came up. Design based on athlete insights make innovations meaningful. Shea deemed the fundamental foundation of all Nike products to be innovation and function, and from there the designer can begin to make the product beautiful.

Hatfield agreed that function absolutely must follow form. Hatfield likes to work in 3D, and says that, at first, the process of meshing different elements does not look very good. But it is a path toward innovative function. He warns his athletes to look beyond appearances the first time they encounter a new product. Most elite athletes understand that function comes first, and trust that Hatfield will eventually make the product look good. Innovation is not about aesthetics; it is about revolutionizing function.

Hatfield also talked a lot about how he is approached specific problems, and developed successful speciality products. He emphasized the importance of listening to and observing athletes, coaches, and trainers. For instance, Nike "Free" was developed by talking to a coach at Stanford about how he manages such successful teams. The coach talked about the importance of avoiding injury, and how his teams avoid a lot of common injuries by engaging in barefoot training. His comment that shoes don't actually strengthen feet really woke up the Nike team, and made them consider the fact that their products had lost focus on the foot itself. So what initially felt like a negative comment turned out to be very positive in the end because it got the Nike team to change the direction of their thinking in an exciting way. Innovation stepped in as the team brainstormed how to design a shoe that would work *with* the foot in a natural way. That's how Nike Free was born.

When Hatfield started talking about Nike's recent foray into the realm of biomimicry, I got tremendously excited. Nike was engaged in a study of camels' feet, and how they are able to resist heat and circumvent sinking into the sand. The design team has been working hand-in-hand with a team of biologists to gain a thorough understanding of the natural mechanics of camels' feet, and are currently working on applying it to a new style of specialty shoes.

But, Hatfield pointed out, sometimes you can stumble upon innovation by accident, without probing and asking specific questions. Be a sponge wherever you go, and take in your surroundings. He says he is an avid people-watcher, and when he goes someplace like the Olympics stadium, he absorbs the trend. What are people wearing? How can we make it better? He finds allowing his mind to wander is a great way to uncover new and unique ideas. Just be able to assess what has good logic behind it, and what is just lazy thinking. A good innovator has to experiment. Sometimes those experiments blow-up in your face, but sometimes they work in unexpected ways. Disproving the validity of an idea can be as important as proving its truth in that it can send you down a different path, or remove a troublesome obstacle from your thinking. That's what he called calculated risk, and he pointed out how many "genius minds" have engaged in this process throughout history, like Leonardo daVinci. DaVinci never would have developed blueprints for the helicopter if he hadn't taken calculated risks, or if he had been afraid of disproving his hypotheses. So maybe the most important lesson you can learn from a great innovator like daVinci is to take smart risks.

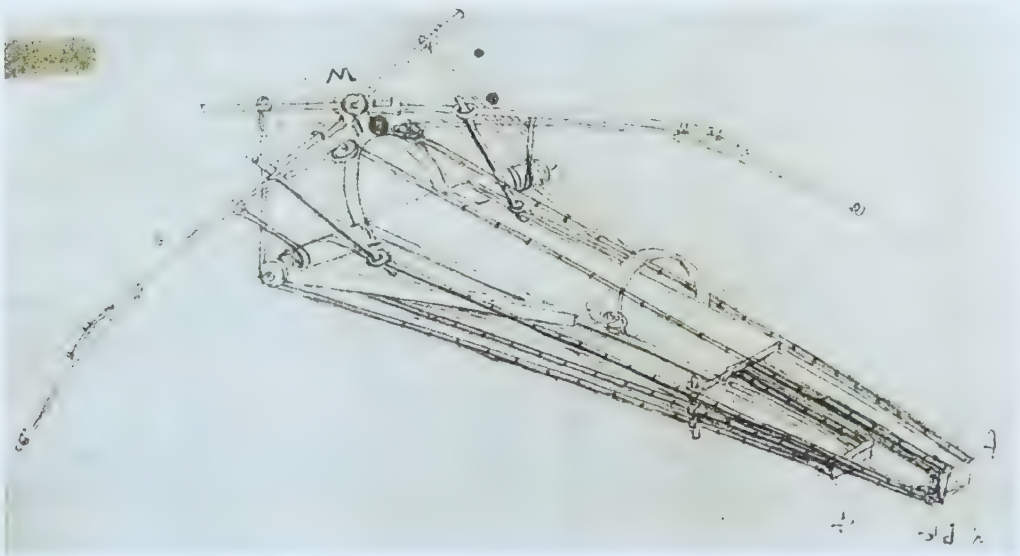

Figure 12 - Drawing of a Flying Machine by Leonardo da Vinci. *Source:* http //ened.tistory.com/category/Leonardo%20da%20Vinci

Before I left, I wanted to hear about the designers' personal sources of inspiration and individual approaches to the design process. Shea got the ball rolling when he named cooking as one of his greatest sources of inspiration. Cooking?! Shea explained that he treats cooking like a design project. You have to think about a lot at once: the end result, who you will be serving the food to, how each of your ingredients will mix, what it will smell like as well as what it will taste like. Shea said he starts every process with questions: who, what, why, when, where, how, and then he welcomes intuition into the process.

Wilson focused on emotional response in his definition of inspiration. He looks for game-changing ideas, simplicity, boldness, confidence, and the ability of a design to educate. He also talked about risks. Dare to believe in yourself and dare to go ahead and do the most profound thing you can think of was his advice. And also, have fun. He said that fun and humor are often underestimated in their value and importance to product design and product enjoyment. Many things can work and result in innovation if they come from a place of passion and truth.

Week 10 – Innovation and Sustainability

I attended a talk by Hannah Jones, who is part of Nike's Sustainable Business & Innovation Team (SB&I). She spoke about Nike's latest initiatives in becoming a more sustainable company, and how that has led to better innovation in their products. For example, Nike has started an initiative called "Nike Better World" to make their products more green. They are currently designing a jersey made out of recycled plastic bottles, and turfs made out of recycled shoes. Jones shared some great advice on the issues of sustainability and innovation.

Jones started out with the general assertion that attaching issues to brands is a successful strategy in that serves both company and cause. She went on to discuss how adopting and promoting sustainability has benefitted Nike. No matter how you look at it, the campaign has boosted the potential for innovation by forcing Nike to face the challenge of how to design the future faster and better than anyone else. The basic mathematical equation of making more with less material demands innovation. Nike has invented new, sustainable materials, a process that is ongoing and exciting. And Nike has worked with various competitors to shape their regulations so that the industry as a whole will have safer factories and workplaces world-wide. This improves the industry and makes Nike's reputation

shine. Basically, Jones said, Nike's goal is to make sustainability an attribute of innovation and performance.

Figure 13 - Hannah Jones, Nike SB&I Team

This talk held a special interest for me given my work with biomimicry. I believe that biomimicry can be an invaluable asset as we strive to shape the future of design by creating innovative and sustainable solutions. Nature is *the* perfect sustainable model, and big companies like Nike have finally started to take it very seriously.

Week 11– Denis Dekovic, Doug Wilkins on Innovation in Nike Football

I spent a considerable amount of time talking to Denis Dekovic and Doug Wilkins, the Design Director and Senior Designer in Nike's Global Football Footwear department. We discussed what distinguishes Nike's football footwear from other brands. Dekovic first talked about what design is, and how a designer should look at and approach design, which is the perfect balance between art and science: 100% art and 100% science Wilkins also introduced Nike's dedication to the athlete. Once a designer

captures the athlete's spirit, that's when innovation begins. Nike takes insights in to performance and drives it into the product, and that is what separates the company from its competitors. A good designer should explore a lot of different ideas, which is great because no designer wants to be handcuffed to a specific recipe for success. Without constant curiosity and openness—to new technologies, new processes, new materials—you might create, but you are unlikely to innovate.

I asked them about the process of developing a new shoe design and how that leads to innovation. Wilkins talked about how he likes to experiment with varied materials, and how the process could differ every time. For example, he could be using a clay to sculpt a plate for the next football cleat, and that would serve as an ideation platform to bring forth new ideas, new shapes, and new geometries, whereas other times he could draw something, or make something with his hands.

Dekovic started out by describing the designer's dream situation: you come up with innovative ideas that are so ground-breaking that they redefine the new aesthetic, so you don't have to worry much about how it looks. But many times, there is no ground-breaking innovation to start with, so you have to choose a starting point: you can start with function, or you can envision an aesthetic, interpret it, and leave the functions and innovations for last. Some people have a very German approach, which is a straight road: consumer insight, then performance, then aesthetics. But Dekovic firmly believes that innovation can be born of a dream. It is all about what will excite the consumer. Once you understand what consumers like and dislike, then you can cull ideas from your own imagination. But if you don't dream, and if you're not open to inspiration, innovation is not going to happen. So some parts of the process require collaboration, but only you can reach inside your mind.

In terms of the evolution of football boots, Dekovic surprised me by pointing out that there has been almost no variation in the field, and as designers and innovators we should be looking at how we can change the industry. One idea which Dekovic encouraged me to look into for my thesis was studying different ways to alter the traction of football shoes by studying how cleats penetrate the turf, what shapes penetrate most quickly, and what shapes offer the most resistance resulting in the most speed. Another major factor that affects performance is control of the ball, which is different on dry versus wet terrain. Football is played in so many different environments—a pitch in Brazil is completely different than a pitch in the US or Europe. And even these general differences change further from day to day, morning to evening, or start to finish of a game. What if it starts drizzling? What if it is dewy and then the dew dries out? The problem is that the traction does not change, it does not adapt to ground conditions, and there is a huge opportunity for innovation there.

So what is next for Nike Football, I wanted to know. Wilkins discussed Nike's work with digital technology, and the goal of working this technology into products that can provide athletes with real-time data. There also has to be a balance between technology and hands-on craft. There is an honesty and humanity inherent to craft, and you don't want to lose that by embracing the digital. So it is a matter of figuring out how to manage the collision of these two realms.

Dekovic left me with some very motivational advice. There are opportunities and inspiration everywhere, he said. You just have to be open to it. Do not waste time on what does not interest you. Focus on what you really care about, and what really motivates you. Do not rely entirely on creativity and splashes of inspiration. Develop your own process, and you will deliver every time something is asked of you.

Week 12 – A Chat with Leo Chang, Russell Stott, and Matt Holmes

During my final week at Nike, I was fortunate enough to interview several of the Design Directors at Nike, including Leo Chang (Nike Basketball Footwear Design Director), Russell Stott (Nike Sports Wear Design Director), and Matt Holmes (Senior Design Director of Global Footwear). We talked a lot about innovation in its current state, and what lies in the future of innovation at Nike.

I wasn't surprised to hear Holmes say that innovation starts with the athlete. We design for the athlete, he said, and our innovations have a specific goal: to make the athlete perform better. Only after he achieves this goal does he start to consider aesthetic features that will make the product desirable, what he calls a "want piece." Some call it the soul of the product, others the story. But basically it is the aesthetic quality that speaks to the consumer.

Chang feels that this kind of "want" aesthetic is achieved by being bold and unapologetic with designs. He sees Nike's separation point from other companies as being a leader in innovation, not a follower. Nike defines the standards in all realms of design, from functional features to color trends.

Figure 14 - With Russell Stott, Nike Sports Wear Design Director

I then asked Holmes whether the focus of the design process should be on functional innovation or aesthetics. He said it should be a balanced split, 50/50. The innovations that exist in a product should be obvious to the consumer. If one innovation is particularly important, it should be showcased and presented in an aesthetically pleasing manner. Part of the designer's job is to make that special innovation iconic.

As always, I wanted to attain a deeper understanding of their processes when designing. Stott talked about how he is often driven by a fear of not doing a good job. He tries to flip that fear around and instead of being his own worst critic, he approaches every project with the goal of doing his best. And when he gets stuck, he looks at the culture around him—books, film, architecture. And when he starts thinking about design ideas, he tries to develop ideas with double meanings. It might sound funny, he said, but he wants an idea that has a deeper significance than what's on the surface.

Holmes' process is data-driven. Everything is driven by data, and data is power. Nike's ability to look at data and uncover opportunities to enhance a product is crucial to innovation. Data-driven design leads

to innovative ideas because the data gives rise to questions which the designer may otherwise have never thought of before.

Chang talked most extensively about his process which, he said, is different every time, for every design. Sometimes a project starts with a sketch, other times with 3D software. He enjoys approaching design projects as problem-solving ventures. Working directly with athletes is very inspirational for Chang, giving his ideas direction and preventing his projects from becoming nebulous and disorganized. He also likes to derive inspiration from observing craft. He may be blown away by a simple seam construction on a bag, for instance. Inspiration can come from any number of places. It is a matter of staying curious and letting inspiration evolve into innovation.

Stott closed the discussion by talking about the future of innovation at Nike. His focus was on a "greener" Nike. He talked about corporate responsibility, sustainability, and how to achieve the lofty goal of zero waste. Hand in hand with those goals is developing more efficient products and manufacturing techniques. Stott feels that the future will be defined by developing ground-breaking products without damaging the environment. Connecting with communities, especially poor communities, and encouraging sports will also be a major goal at Nike.

The Nike mark has been around for almost 40 years. It is recognized by people around the globe, and it is Nike's responsibility to maintain the integrity of that mark. Designers should follow this ethos, and stay innovative without trying too hard or going too far off track. Sometimes people throw lots of additives on a product to make it desirable, when it is the brand itself that should entice customers. It is a challenge to find the balance between doing something new, and staying true to who you are and what you stand for. Just because another brand is doing something does not mean you need to do it. A designer should be aware of the trends without letting those trends have too great of an influence on their own work. A great innovator is not necessarily a great leader. A lot of brands have gone out of business by losing focus of their core and chasing trends. People stick with brands that are consistent. Like Nike.

3.2 Inspiration Trips

A huge part of working as a Nike designer is taking 'inspiration trips'. Nike grants its employees the opportunity to travel to different countries to study foreign cultures he or she has never been exposed to before. Having experiences that are off your "radar" and that push you to explore beyond your areas of interest can inspire radical new ideas to manifest in your practice. The whole idea of travelling is to be a sponge. It teaches you how to observe and not take anything you see for granted. You begin to notice detail, and to be more appreciative of your surroundings, skills that are essential to any great designer.

So after I completed my internship program at Nike, that is exactly what I did. I took a trip to the Middle East where I visited three different countries: Bahrain, Kuwait, and the United Arab Emirates, and studied traditional design techniques. I studied form, patterns and textures, different design techniques and how to use unusual design materials. I also had the chance to observe and talk to some of the few remaining artisans and masters of these traditional techniques, which are, sadly, slowly starting to disappear. Below I have highlighted the most interesting parts of my trip, and shared several different techniques that I learned. Overall, what struck me is how the traditional techniques I encountered are free of any chemicals. They always make good use of nature, employ natural materials in a sustainable manner, and imitate natural processes. Since having had the opportunity to study these nature-based processes more closely, I have begun to utilize them in my own practice by mixing them with other techniques with which I am already familiar. As referenced before, I have been looking to Frans Johansson's ideas in his book, "The Medici Effect", for guidance on how to find new intersection points between the old and the new that can lead to innovation.

Palm Trees

The Middle East is known for its lustrous palm trees, and in Bahrain, palm trees are everywhere. Bahrain, a tiny island that was once known as *the land of a million palm trees*, was the first stop on my inspiration trip. Palm trees struck my interest instantly because they are completely sustainable and offer a variety of benefits. They produce more than 50 different kinds of delicious-tasting dates, and after the dates have been picked, every single part of the tree can be used for a different purpose. In the old days, many houses where made out of palm leaves and bark, allowing the inside of the house to cool off in hot climates. Learning this fact automatically set me thinking about how I could utilize this concept and material in my own product design, be it a self-cooling shoe or automobile for hot climates. Needless to say, I was interested and inspired by all the benefits the palm tree offered, and during my time in Bahrain I spent a good deal of time studying two different techniques that utilize palm materials, weaving palm and making palm tree papers.

Palm Trees: *Weaving Palm*

Weaving palm is a traditional process that has been used for 100's of years in Bahrain, but only a few masters remain in the country. The craft entails weaving palm tree leaves into two-dimensional and three-dimensional objects. For example, the "Sufra," which is a mat placed on the ground where a family gathers to eat meals, is made out of palm tree leaves. These same leaves are used to make baskets. Weaving palm is a complex process and consists of several stages, starting with the gathering of palm leaves. Collecting palm leaves is more difficult than it sounds. The gatherer must seek out newborn leaves that are only found in the heart of the tree. These leaves have not yet turned green, and have a much moister feel than mature palm leaves. Once a sufficient amount of leaves has been collected, the leaves are dyed different colors. Next, the weaver must figure out the architecture of the design. Most shapes require the use of a support material, and the most common support is part of the leaves' stems. Only then does the real artistry begin: weaving.

What fascinated me most is how flexible yet strong the palm-leaf objects are. They don't break, they are lightweight, and they hold their shape infinitely. I couldn't stop thinking of all the possibilities this material holds for modern product design. I was also amazed by the sustainability aspect of palm leaves. Let's say you buy a palm-lead basket. What happens if it gets damaged, or you decide to get rid of it? In the case of damaged leaves, they can easily be replaced or mended. And if you decide you no longer want the item, you can recycle it easily by passing it on to the paper makers!

Figure 15 - Palm weaving

Figure 16 - Palm weaving

Figure 17 - Woven basket

Figure 18 - Woven pattern

Palm Trees: *Palm Tree Papers*

So what are palm tree papers? A palm tree paper is an amazing and innovative way of making 100% sustainable paper out of palm tree leaves. So yes, if you decide you no longer want something made out of palm leaves, then the best action you can take is to pass it along to the paper makers. Bahrain is the only Middle Eastern country that uses this technique, but hopefully it will spread. The process requires five basic steps:

Figure 19 - Process of making paper out of palm tree leaves

1- Wash palm leaves thoroughly, then leave them to dry and harden.

2- Cut and shred the leaves into small pieces.

3- Grind the leaves and combine with the "secret recipe," until the leaves become a mushy consistency. Let this cook for 8 hours. Dyes or scents can be added during this process.

4- Pour the mixture onto netted wooden screens that are resting flat across a table to soak the water out. Spread mix evenly, according to desired size and thickness of the paper

5- Take the flat sheet of paper out and let it to dry for one day, then iron it smooth.

You can make all kinds of paper with this technique, from normal notebook paper, to canvas-like sheets for drawing and painting. This is a completely sustainable process, so if you take any piece of paper and cut it up, it could all be repeated to make new paper.

Figure 20 - Process of making paper out of palm tree leaves

Pottery

Clay pots and pottery are a popular traditional art in Bahrain. This art not only requires a very skilled artisan to shape the clay, but also requires that the artist knows a lot about the clay itself. A lathe machine, which is a round table that spins from the pressure of a foot pedal, is used to shape most of the clay products, but some items are hand-crafted, especially if they are larger scale or a shape other than round.

Figure 21 – Pots hand made out of clay

A clay master has to perform a six-step process which I found just as interesting as the final product itself.

1. Large quantities of special sand that is a specific color and texture are brought in from the desert, brought to the factory, and dumped into a big pool.

2. The pool is filled with water and mixed with the sand for several days, allowing the dirt and stones to rise to the surface, and leaving the bottom sand very soft and pure.

3. After the mixing and separating is complete, the water is drained into another pool, leaving behind the clean sand which has by now turned into a soft, damp mud. This mud is gathered into big piles and covered for several days as it cools.

4. This mud, or clay-like material, is broken down into small lumps, sized according to what the clay-master is going to make, and placed on a lathe table. The master starts shaping his clay product, carefully measuring the symmetry and balancing the proportions as he or she spins. This old process was really interesting to me because it is also used in carpentry and modern, digital 3D Programs, which work off the same concept of creating objects out of a line that revolves around itself.

5. Once the pot has been carefully molded by hand, it is placed in the sun to dry. After it has dried, it is once again placed in a tub filled with water. At this stage, any pot that does not look right or that has cracks is broken up and taken back to the filtering process to start over. Re-using whatever is defected ensures a maximum sustainability that is lacking in modern manufacturing.

6. Once the clay has been inspected and deemed good to go, the product is placed in a small fire chamber, where the heat hardens it. Once the product is solid, it is coated, colored, and decorated before hitting the market and going on sale.

Figure 22 - Placing pottery into the fire chamber

Weaving Thread

Weaving thread is another amazing art that caught my eye while travelling. The technique and machinery was the same everywhere, but regions used different materials, and the threads differed in thicknesses, durability, texture, and color patterns.

Figure 23 - Weaving textile

The weaver sits on the same level as the threads, and toggles the two harness frames with his feet. When he presses the pedal-shaped lever, the two harness frames witch sides and move up and down, cross-hatching each other. Every time the two frames go up and down, the weaver pushes a wooden piece called the "Shuttle", between the threads. The shuttle has a piece of spool inside it, and different colored yarn are spun around this spool as the shuttle slides back and forth. This is how the textile is actually made. By using different colored threads, the weavers are able to make cloth with magnificent patterns and varied textures.

This trip was the first time I had ever witnessed weaving, and it got me really interested in how this method could be applied to modern product design in a new and innovative way. The possibilities of what I could pull away from it in terms of color, pattern, materials, and texture are numerous.

Figure 24 - Part of the weaving machinery, called the "Kareeb" in Arabic

Calligraphy

The final inspirational art I will discuss is the art of calligraphy. Arabic calligraphy is a beautiful and ancient art that brings peace of mind both to the calligrapher and the viewers. Just a few beautiful strokes on a clean canvas create a powerful impact because each stroke contains a wealth of feeling and emotion. What I love most about calligraphy is its simplicity. It can be executed quickly without losing any of its power or elegance. Interacting with calligraphers taught me an important lesson: never disregard details. It also reminded me of something I heard at Nike: "Experience excellence." Absorbing the excellence of artists and athletes in all fields is an amazing source of inspiration, and using that inspiration may produce more excellence.

Figure 25 - Arabic calligraphy. *Source:* http://www.xtimeline.com/evt/view.aspx?id=89071

3.3 Bike Case Study

After all these new experiences from my internship and my Middle Eastern inspiration trips, I was ready to launch a new project. I decided to design a bicycle because I wanted to challenge myself and explore my design approach in new ways. I knew that undertaking a bicycle design would push me to experiment in new realms, and would grant me enough creative space to experiment with some of the ideas I learned at Nike. I had designed cars before, and several other vehicles, but this project entailed an extra challenge. I was curious to measure how much, if at all, my thinking had changed, and how much my recent experiences had affected my decision-making process and the aesthetics of my designs. Below I describe the bicycle and its innovative features. In addition, I will analyze the reasons for my design decisions in light of the new experiences from the Nike internship and my inspirational trips.

One of the things that Nike always focused on was innovation through collaboration; therefore, I would like to give credit to my great teammate, with whom I collaborated on designing this bike, Marin Myftiu. This collaboration truly opened up new perspectives for both of us as we brainstormed and worked our way through the design process.

The nCycle

Although e-bikes (electric bicylces) are a fairly recent invention, and possess great potential, the vast majority of current e-bikes rely upon 100+-year-old designs and you can tell it just by looking at them. To most people, e-bikes are only distinguished from traditional bicycles by their odd and clumsy appendages of tubes, wires and extra electric hardware. Even the sleekest looking bikes are traditional designs dressed up in "iRobot clothes". Our lifestyles and needs have changed dramatically since the late-19th century, and our designs should follow suit. As it stands, these structures are unnecessarily complicated and not really up to the task of offering the minimalist aesthetics and extra functionality that our digital age demands.

Keeping the basic mechanics while scrapping the structure gave Marin and me the chance to adopt an innovative approach to the e-bike design which resulted in more than just a bicycle. We developed a framework for a whole lineage of future e-bikes. By problem-solving from the ground up and integrating functionality into the aesthetics, we designed the nCycle, a design offering functionality and optimal electric power in radical new ways.

Figure 26 - The nCycle, 2013

nCycle philosophy

Price is the most acute concern in the e-bikes market today. Marginally-effective systems, such as battery drive, drive both the cost and weight of e-bikes sky high. An e-bike can do away with their current power aids and electronic controls, devices that most cars do not even have. The resulting lighter frame and lower price will increase mass-market appeal.

In order to house the new functions, a pair of metallic sheets is attached to the nCycle in parallel fashion at several points that connect to the main mechanics. These sheets house the vital electronic and electrical systems that run the bike. This is lightweight and inexpensive, making the nCycle cheaper, sturdier, more flexible, and easier to build and maintain.

nCycle's Objectives

Cost reduction: With today's demand to bring down our energy and monetary consumption, e-bike prices of $4000+ create a substantial drawback when it comes to marketing strategies and sales. The

main objective is to develop a cost effective design that can be developed into an e-bike with different options on its features.

Native integration of new core functionalities and structure design: Many current e-bikes, like the Smart Bike or Mercedes Bike, offer extras like electronic gear control or electric drive. However, these functions all depend upon a legacy tubular structure that makes them more vulnerable to theft and/or damage. They also complicate the building process, thus increasing costs. Our goal is to redesign the e-bike structure completely so that it possesses the frame strength and integrative capacities to incorporate such extra functionalities as core features.

Ability to transport objects: Most bicycles do not offer a means to transport even the smallest object. Redesigning the structure of e-bikes will increase the ease of object transport.

Seamless integration of elements: As many features as possible, such as brakes and lights, will be integrated into the base design to work in technical and aesthetic harmony.

Distinctive Look: Despite their simplicity, bicycles often look and feel complicated, and e-bikes even more so. This revolutionary approach demands a new look that fuses aesthetics and functionality, giving the nCycle a user-friendlier feel compared what already exists in the market.

Problem solving

After making a thorough cultural, technical and practical study of the bicycle, we have tried to address some of the yet-unsolved shortcomings the bicycle suffers in modern society. By informally interviewing several regular bike users, we developed a list of features that bicycle riders desire, but that bicycles lack. We used this list to develop the nCycle's innovative structure.

Built-in cargo

By far the most annoying situation for a modern bicyclist is the struggle to transport an object that cannot fit in your pocket. If you don't have a backpack or a basket. You either have to leave your bike somewhere, or drag it with you, along with your load.

It seems like the only solution is a bulky basket or back grille, but the nCycle offers a natural solution by offering a retractable pocket between its two metal plates. The pocket disappears completely when not in use and only shows under the belly when it is filled. Because it is tied to two rigid, folding arms, the support of the pocket makes it foldable and flexible, but also sturdy and unbending while turning and tilting the bike.

Figure 27 - Visualizing the folding mechanism, the nPocket

Handlebar and lock

Another annoyance for many bike-users is the chain lock. When you ride, you are forced to lug it around aimlessly, and it often bumps and scratches the frame. Other times you desperately need to lock your vehicle, but realize that you have forgotten your chain. In addition, chain locks are heavy. Instead of a problem, we viewed the lock as another opportunity for innovation, and developed a great compromise: a solid, handlebar-mounted locking system.

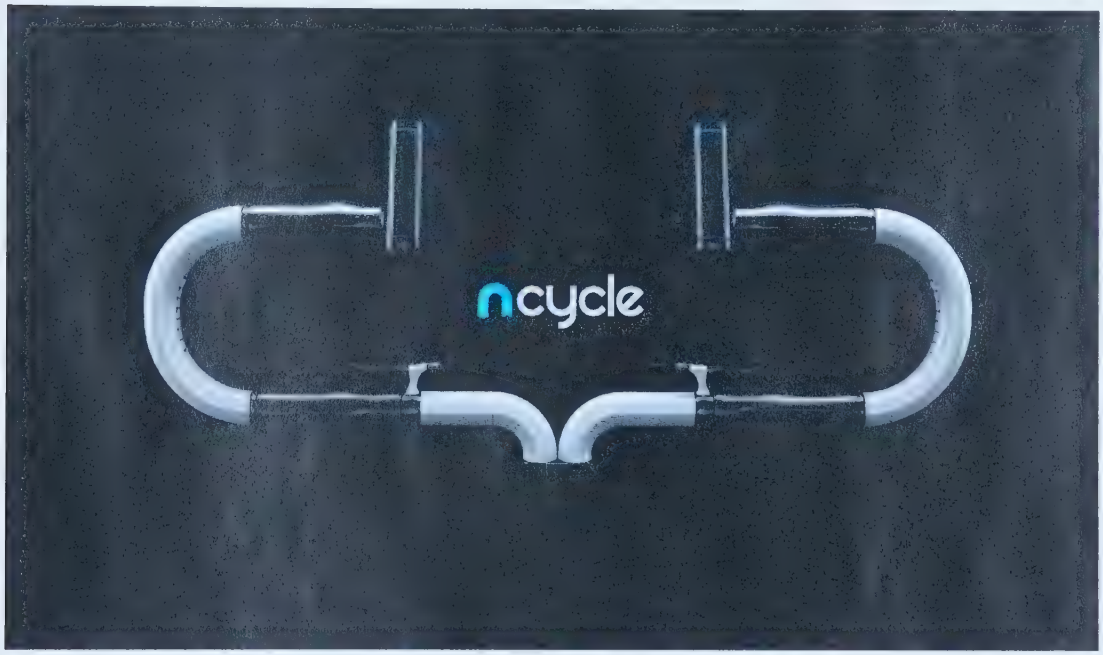

Figure 28 - Self locking handlebar, the nLock system

The new integrated locking system offers a blend of safety, portability, and ease of use. Doing away with cables, most of the system consists of the handlebar itself. It offers dual handles for multiple positions and optimal comfort. A hardened steel tube slides from one of the handles and closes completely to lock the bile, making the lock virtually impossible to break with any kind of man-powered pliers. Additionally, the handlebar is appropriately loop-shaped to fit most of the poles and steel bars available in any city.

Additionally, the lack of cable or chain makes the whole, laborious process of locking and unlocking much quicker and simpler; you just embrace the pole with the handle, pull the tube from one handle

and click it inside the other. The handlebar can be rotated 360° and locked into different positions. And best of all, cyclists don't have to tote any additional appendages around.

Headlights and speakers

For cyclists, a significant safety feature is headlights. In a few countries they are mandatory, but for the rest, they are almost nonexistent. The problem is, again, lack of integration and removability.

Headlights are built-in to the nCycle handlebar. They are powered by an integrated battery that is neatly fitted within the two sheets of the body and located between the pocket and the handle bar axis. The aggressive, animal look fits nicely with the overall design, and because integration is one of the key aspects of good design, the rear of the headlights also houses an integrated system of Bluetooth speakers. The built-in speakers are embedded in the structure of the headlights and are able to connect with any compatible design by Bluetooth. The speakers are also powered by the onboard battery and require no power from an external device.

Figure 29 - Front headlights and speaker system

Folding

Folding bikes are generally clumsy. They look odd and "chunky", and are often a burden to carry around. Most sleek designs never make it into production, and those that do are exorbitantly expensive. Again, thanks to its special sandwich structure, the nCycle can be folded quickly, without suffering from any aesthetic or aerodynamic handicaps when operating.

Figure 30 - Self-locking and folding system

The frame folds in an innovative way. The body of the nCycle splits in half at the point between the seat and pocket. A pair of rails is attached to both parts and the hinge is made to slide along those rails. So folding the bicycle involves just three simple steps:

1. Unlocking the rail
2. Sliding both ends to uncover the hinge
3. Folding

Electric/Electronic system

Although many e-bikes currently in production and on the market boast smartphone capabilities, we believe that placing a touch smartphone in a speedometer-like bracket on the handlebar of a bicycle for direct operation is an uncomfortable and potentially very dangerous feature. The nCycle offers a safe alternative. A big, holographic display replaces the phone on the handlebars, creating easy visibility. The phone rests safely in a dock on the body of the bicycle, using an app to control the display. The various functions of the app can be accessed by sliding the thumbs back and forth on touch sensitive zones near the handles, without requiring the cyclist to remove his or her hands from the handles.

Figure 31 - Cross section showing the inside parts of the nCycle

All of this will be powered by the default lithium battery located between the pocket and the handle bar. Its main functions are to supply power to the front and rear lights, the wireless front speakers, the holographic display, and to simultaneously charge the smartphone placed on the dock directly above it.

Electric drive

Another attractive feature of the nCycle is the electric drive. The vehicle is partly powered by a rear hub mounted electric motor. The drive power battery is located inside the body, starting from the seat and running up to the pedals hub. The structure not only offers natural shell protection to the battery, but being metallic, it also provides substantial cooling, which enhances performance and increases battery life. Although the electric drive will probably increase the cost of the model, it has substantial benefits that will ultimately save the consumer in future investments, such as battery repairs and replacements.

Versions

The nCycle will offer several different models to satisfy the needs of a wide range of riders.

Bionic – This is the standard equipped e-bike which offers the following basic features:

Integrated fold-up pocket

Phone dock

nLock locking system

Headlights and speakers

Holographic display

Bionic, Foldable – This offers the same features of the bionic model, but in foldable form.

Electric – Adds electric power functionality to the bionic model.

Electric, Foldable – Electric-powered foldable model of the bionic.

Ideas and Inspirations

Once I finished designing this bike, I took a step back and tried to understand my process on a deeper level. Tinker Hatfield, VP of design at Nike, told me, "Your designs are a result of everything you have seen or experienced in life," and I tried to uncover the connections between my experience and my design. I think that designers tend to get too focused on the idea of what makes a process "good," and they get stuck, because there is no correct formula. Like Hatfield, I believe that good design stems from the sub-conscious mind, and grows from past experience and inspiration. My analysis as to what led to my design decisions in developing the nCycle remain just guesses, but it is always interesting to work your way backwards and try to understand why some things have happened.

I couldn't help but pinpoint the self-locking handlebar system to an experience I had on my latest inspiration trip. Once of the toys that Bahraini artisans make of palm leaves are called "Chinese Finger Traps." The leaves are woven into narrow tubes. You stick your fingers into both sides of the tube until it sticks, locking your hands into place. The new locking system is based on a similar concept, but executed in a slightly different way to more accurately fit the desired function.

Figure 32 - Chinese finger traps. *Source* http://tacunited.files.wordpress.com/2013/03/chinese-finger-trap.jpg

I can trace the integration of "extras" such as headlights, carry-on spaces, and speakers into core features of the bike, to the ethos of sustainability I witnessed in the palm paper and pottery processes. I translated that sustainability into the ability to centralize the functionality of the product into one place by making it all part of the product itself.

Sometimes others made the connection for me. For example, *Core77* wrote a review of the nCycle, describing the bike's form as having "a human feel." The writer compared the aesthetic sensibility of the bike to the Mark Jenkins work, *Couldn't Resist*. It was great to observe and learn from someone else's perception of my work.

Figure 33 - *Couldn't resist. Source: Mark Jenkins,* http://www.xmarkjenkinsx.com/

I could make countless assumptions about what led me to make certain decisions, but to be honest, there are parts of the process that I just can't seem to connect to my past experiences in a direct way. These things probably go too deep into my sub-conscious for me to access. But this process of working backwards and analyzing my decisions has opened my mind to the endless possibilities for innovation. For example, what if the pocket idea may have come from a kangaroo, and what if the wheels could have come from a seagull beak that has a hole in it. These thoughts made me think deeper about, "what if." What if I had really looked at a seagull's beak for inspiration when designing the wheels? Why is there a hole in a seagull's beak in the first place? Does it have any additional effects that I overlooked at first glance, and that I could link back to design? These questions have led me to investigate further possibilities and achieve a deeper understanding of why nature has these forms, and how they affect the function of the design.

3.4 Path to Biomimicry

Each of these experiences has introduced me to new perspectives and led me down different paths toward innovation. Working with a company that is a global leader in design innovation, taking inspirational trips, collaborating with other designers, and questioning my own decisions have all led me to biomimicry. These experiences have given rise to questions about nature, its diversity, functionality and natural "innovation".

My experiences at Nike led me to new ways of thinking. I learned the importance of seeking inspiration from many different places, and how to "sit with" new ideas and let them grow into something unique. As a designer, I have learned to stop seeking the "right" formula and to listen to my own instincts, even when I'm not sure if they are correct. The fearlessness that is promoted at Nike is a crucial trait for a great designer to possess. If I'm afraid to take risks or to defy the norm, I will never create anything that is truly innovative. Innovation has to be bold, radical, and to chart new terrain. Fusing biomimicry with modern design techniques will do just that. The natural elements that I incorporate into my designs will speak to people's most basic desires and needs so that they are able to relate to my designs in a new but natural way.

My inspiration trips really solidified my passion for biomimicry, especially in the realm of sustainability. I was drawn to the holistic approach that is used in 3 of the crafts I observed. Those crafts imitate nature in that they have a complete, sustainable life-cycle rather than one specific short-term function, like so many products that cause waste and pollution problems. Bringing those traditional techniques and that natural sensibility to modern design will result in revolutionary innovations. Society will be inundated with sustainable products that have longer life-spans and improved functionality, because nature is the unparalleled master of perfect function.

These experiences have given me a wealth of inspiration and excitement. Biomimicry is a field where all my experiences intersect and point in the same direction: toward true innovation. I have attained a deeper understanding of nature as a limitless resource for any designer, I see no boundaries to how biomimicry can revolutionize the design world and, ultimately, society.

4. Problem Parameters

In this chapter, I will discuss different design functions that have the potential to become an integral part of my design process, and that are largely inspired by the functions and beauty found in nature. My objective is to study several interesting functions of several different species, compare and contrast them, and to apply my findings to a case study – where I design a car as a case study, that utilizes at least one of these nature-based functions. The design problems I have set for myself, which will set the parameters of my directions accordingly, are:

1- ***Thermoregulation***: Creating a more energy-efficient yet effective air conditioning; specifically, how can we develop a ventilation system that would serve well in countries with extreme weather conditions?

2- ***Light Weight and resistance:*** Cutting down on a car's weight means being more energy efficient; how do we decrease weight while maintaining strength and stability to ensure safety?

3- ***Vision:*** Side mirrors on many cars have blind spots which can be dangerous for the driver and other drivers on the street; what can nature teach us about designing better side mirrors, regardless of the shape of the car?

4.1 Thermoregulation

Thermoregulation is an amazing and efficient feature found in a many species. When it comes to regulating body temperature, species are split into two groups: endotherms and ectotherms. Ectotherms, also known as cold-blooded animals, warm their bodies by absorbing heat from their surroundings. These animals tend to have a lot more variation in their normal body temperatures due to their changing environments. Most invertebrates, fishes, reptiles, and amphibians are ectotherms. Endotherms, also known as warm-blooded animals, depend on the heat produced by their own metabolism. Endotherms tend to have a constant body temperature even if they are in environments with varying temperatures (Lacey et al., 2010). Understanding the process by which endotherms maintain a steady body temperature will be key to developing an effective thermoregulation feature for the car design, and any future products that require such a function.

In general, endotherm warming is regulated by the metabolism. Prevention of heat loss is achieved by way of peripheral blood vessel constriction. Cooling is caused by peripheral dilatation, convection and evaporative cooling. The most efficient way for any animal to cool down is to evaporate water, by way of the respiratory system or the skin (Mitchell & Skinner, 2004). Evaporation is effective because 1ml of water can be turned into water vapour with about 2-3kJ of energy , and the only source of energy used in this process is blood heat; thus, internal cooling occurs. The consequence, however, is that the water lost by evaporation needs to be replaced to prevent dehydration.

The first example of a great thermo-regulator that I investigated is the giraffe. Giraffes live in extremely hot weather conditions in Africa, yet they manage to control their body heat very effectively. Biologically adapting over millennia, the giraffe skin serves two highly unique functions. The first is the tautness of the skin, which functions as a G-suit (a tight and flexible suit), allowing the giraffe to achieve high speeds of acceleration. The second is its camouflage aspect, which allows giraffes to easily remain hidden from predators (Hargens et al., 1987). The pattern on giraffe skin looks like patches, making giraffes almost invisible when amongst shrubs and trees (Langman, 1977; Mitchell & Skinner, 2003).

The patches on giraffe skin serve another highly-significant yet unsuspecting function: thermoregulation. Science first took note of this feature in 1927, when a scientist named De Beaufort discovered that large blood vessels within each black patched area of the skin. This idea was later studied and expounded upon by Errol Ackerman (1976).

Ackerman dissected the anatomy of the patched areas on the giraffe's skin, as shown in Figure 1. He showed that below a patch there are 2 main veins, a large one that is about 30 mm below the skin, and another smaller one about 10 mm below the skin, which has a network of smaller veins and arteries branching out of it towards the skin (Ackerman, 1976). Thanks to this network, a giraffe's body is able to send blood from the bigger vein to the smaller vein, and out through these smaller veins and arteries, releasing heat and allowing the animal to cool off (Dugan, 2011).

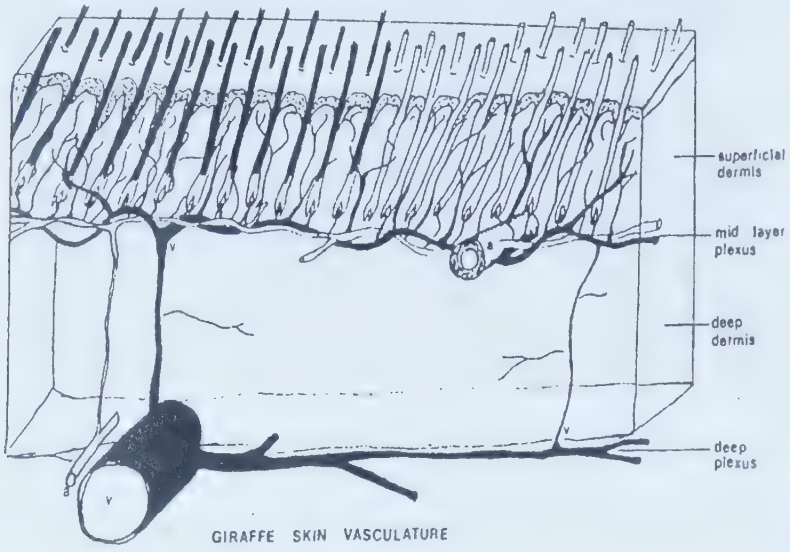

Figure 34 - A diagram of the skin vasculature in giraffes showing the deep and mid layer plexuses of blood vessels
Source: (Ackerman 1976)

The thermoregulation abilities of giraffes remain an area of interest amongst the scientific research community. In 2004, Mitchell & Skinner collected skin samples from 46 different giraffes in different areas and analyzed various aspects of the skin's anatomy to better understand how the giraffe's skin achieves thermoregulation. Sabine Hilsberg (2002) also conducted several studies on giraffes and their skin anatomy from a more skeptical standpoint; questioning whether or not they truly serve as thermal windows. He performed several investigative studies using infra-red images of a giraffe, as shown in Figure 2, to highlight the different temperatures of different points on the giraffe's body. The infra-red imaging consistently showed the patches to be the hottest spots on the body, clearly indicating that there is thermoregulatory activity occurring in these areas. These studies and observations all conclude

that the dark patches on the giraffe's skin serve a crucial function as thermal windows that release heat and regulate its body temperature (Skinner and Smithers 1990).

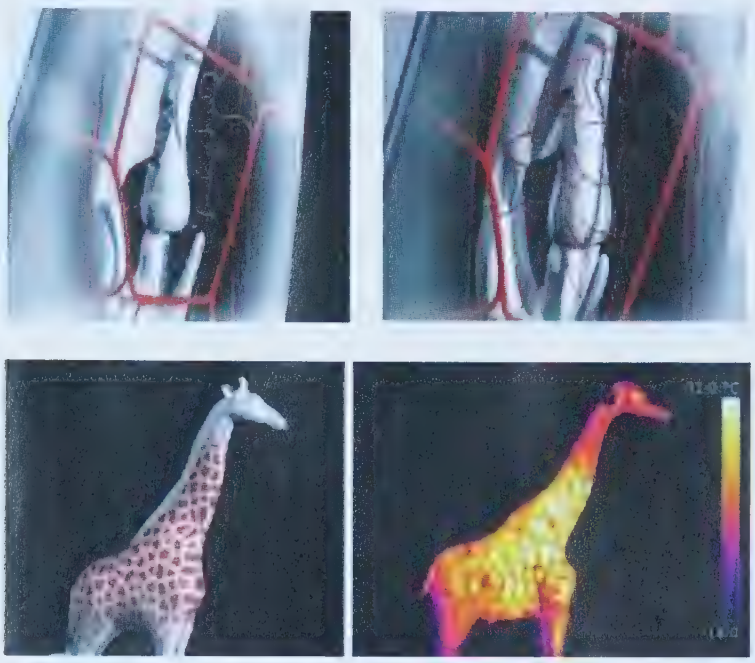

Figure 35 – Visualizing the giraffe skin patches ability in regulating temperature.
Source: http://www.giraffeconservation.org/giraffe_facts.php?pgid=5

Giraffes are just one interesting example among many. Other animals living in extreme weather conditions are able to regulate their body temperatures just as effectively, in their own unique ways. The elephant, for example, does not sweat, but instead releases heat through its huge ears to regulate body temperature (Buss & Estes, 1971). Elephant ears are packed with small capillaries, and when the animal gets hot, the blood flows to these capillaries, which lowers the temperature of the elephant's body. In other words, the large ears of elephants are like large, flapping convection plates, transferring heat from the elephant's body back to the environment (Narasimhan 2008).

Another example of effective heat regulation in the animal kingdom is the large beak, or bill, of the beautiful toucan bird. The toucan bill is considered to be one of the biggest thermal windows in the animal kingdom, rivaling the thermoregulatory ability of almost any other animal (Tattersall et al., 2009). The yellow and orange bill of the average toucan comprises approximately one-third of its total body size, and is packed with a network of superficial blood vessels (Midtgård 1984). As the beak is large in

size, un-insulated, and well-vascularized, it is able to act as a thermal radiator (Scott et al., 2008). As the heat exchange and heat control happens through the beak, the area around the eyes is very well-protected, and its temperature remains almost constant (Klir et al., 1990). Infrared footage from different studies also shows the different levels of heat control within the beak at different times of the day, further clarifying the function of the beak as shown in Figure 36 (Scott et al., 2008). The highly vascularized areas work similarly to the way it does in giraffes, and so does its large size and surface area it covers. In the next section I take a look at the structure of the beak, which has its own benefits and other features as well, but could also possibly play a role into thermoregulation.

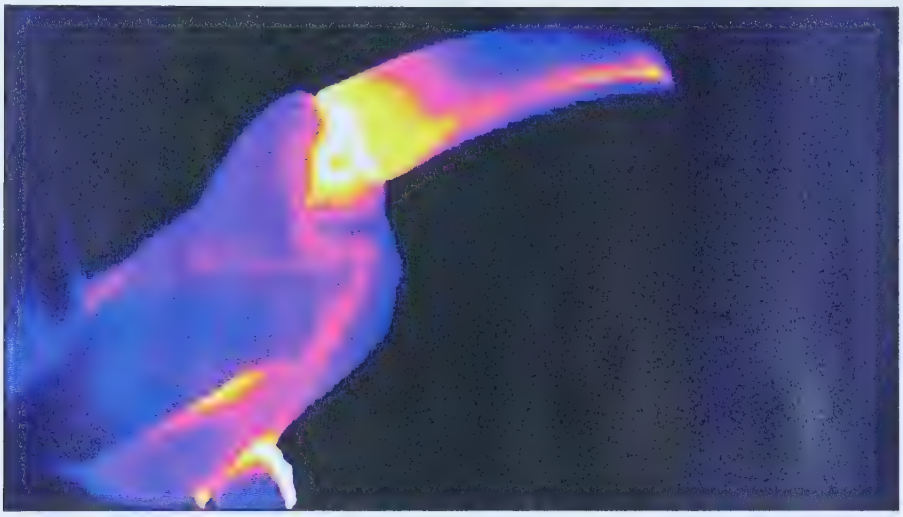

Figure 36 - A picture of a toucan at night taken by a thermographic camera.
Source: http://news bbc.co.uk/2/hi/science/nature/8165895.stm

Not only animals but numerous plants also possess amazing thermoregulatory mechanisms, which is especially important in climates where the heat and humidity is extreme. One great example is pine cones. The scales on pine cone respond to the weather, opening up when they are dry and closing when they are damp, or wet. The scales consist of two layers, internal and external, and both react to changes in humidity. When exposed to dampness, the cellular tissue of the external layer expands horizontally, which causes the scales to close. The internal layers mimic this process. When the environment is dry, this same tissue contracts, causing both the inner and outer scales to open (Ternaux, 2012).

Schoeller, a Swiss company that develops innovative materials and textures for footwear and other apparel, recently came up with a material called C-Change, which is inspired by pine cone scales. The material has a membrane that opens up during heat-generating activity, or when the body starts to

sweat, in order to cool off the feet. It does the opposite when the weather is cold, and the membrane contracts to keep the feet warm and more protected ("Bionic Climate Membrane," December 15, 2006). I was introduced to a similar material during my internship at Nike, by Thomas Walker, Senior Design Director for Apparel in Nike Running. The material is called SphereReact, and it consist of small pods that open and close based on the temperature and sweat level of the athlete, acting as a smart material to give the athlete maximum comfort.

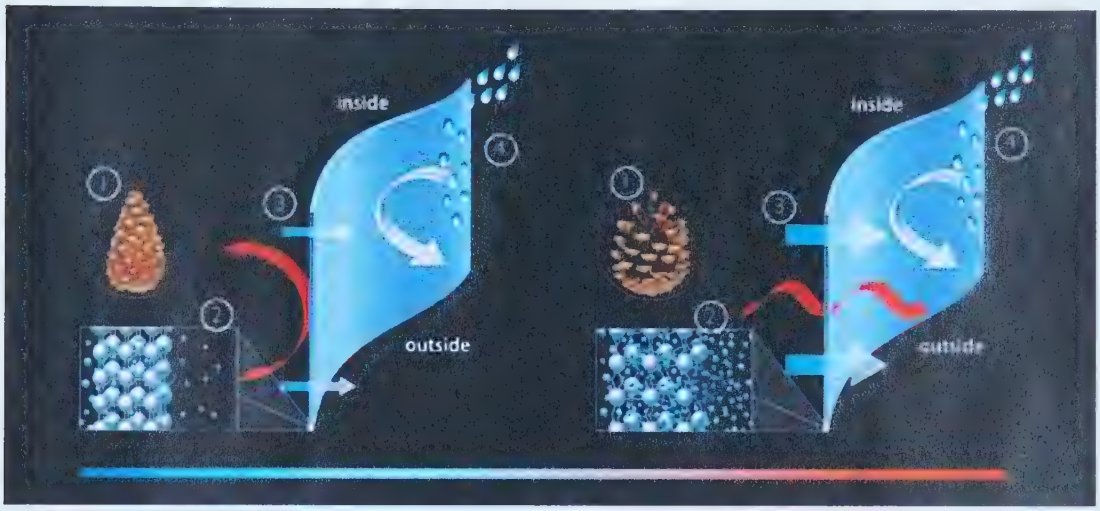

Figure 37 - The C-Change material from Schoeller, inspired by the pine cone.
Source: http://www.schoeller-tech.com

In contrast to this high-tech, man-made material, I encountered a similar concept during my travels to the Middle East. The local people of Bahrain and other regions of the Middle East, who endure an extremely hot climate, make great use of palm tree leaves. In the old days, people used to build small huts, baby cradles, and daily-use items such as baskets and bowls, from these leaves. They function well in hot conditions as they create shade and cool down interiors by absorbing heat.

The above exhibits how a variety of species share the ability to regulate body temperature through a range of unique features and functions, from the capillary-packed surface of elephant ears to the temperature-responsive pine cone scales. These naturally-occurring and highly-efficient heat regulatory systems are a gold mine for any designer seeking innovative solutions. There are countless other thermoregulation systems to be found in nature, which can be particularly useful to designers who are seeking new ways to approach energy efficiency. Thermoregulation stands as testament to the vast range of techniques to be found in nature, and the many different ways they can be applied to product

design. The opportunity to merge these unique systems and very different ideas, and find new points of intersection, is an exciting path to true innovation.

4.2 Lightweight and Resistant

One of the most impressive features found in nature is the ability to increase strength without increasing mass; a property which could benefit many modern products. This property can be found in multiple species and organisms in nature, such as toucans, mountain sheep, bee hives, and trees (Tarneux, 2012), to name only a few. I will observe several of these species to discover how they maintain this seemingly contradictory balance, while achieving optimal functionality.

The first example is the toucan. As referenced in the previous section, the toucan beak comprises one-third of its total body size, which is enormous compared to any other bird. But despite its large size and volume, this huge beak only accounts for 5% of the toucan's total mass. Yet its strength is incredible; it is almost impossible to damage. Even if a toucan suffered a direct collision with an obstruction such as the branch of a tree, it would possess enough impact-resistance to remain unharmed (McKittrick et al., 2012). To understand how the toucan beak can possess such strength and resistance to force in combination with such a low physical mass, scientists have closely studied the beak's anatomy, and the substances and structures crucial to its construction.

The outer shell of the beak is made up of layers upon layers of a material called keratin, the same material found in our finger nails. These layers are bound together tightly, as if laminated. Behind this outer wall of keratin, the interior is a thick layer of a foam-like material, made of bony fibers and drum-like membranes (Fecchio et al., 2010). Finally, below the foam-like material, the beak has a hollow region where mechanical stress becomes insignificant. It is an amazingly smart design, because the hollow areas eliminate the need for complicated structural support that would add to the weight of the beak (Bodde et al., 2011). This concept could be interesting to test in modern product design when addressing the problem of extra weight and bulk that too often accompany increased strength, support and efficiency. The foam could also work as an airflow system, carrying cool air through its pores from one side to another, covering a large surface area.

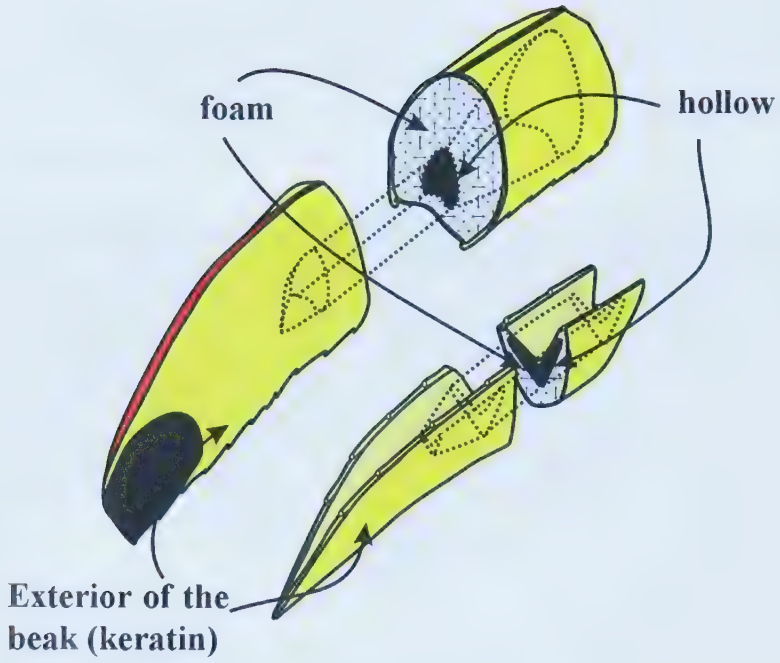

Figure 38 – Structure of the toucan beak.
Source: http://www.jacobsschool.ucsd.edu/uploads/news_release/2005/Toucan.beak.schematic.jpg

The foamy material found inside the toucan's beak is similar to many other spongy forms in nature, including the Venus Flower Basket. The Venus Flower Basket is a kind of sponge found in the deep ocean, belonging to the class of Hexactinellides. It is also called a "glass sponge," or "shrimp sponge." The majority of sponges have no defined shape, and grow in unpredictable ways, sometimes adopting the shape of the rock they grow on. All sponges have one characteristic in common, which is a porous surface that allows water to penetrate and provide it with food and oxygen. What makes the Venus Flower Basket unique is that it *does* have a defined shape, in the form of a beautiful curved tubular skeleton that can grow up to 1m in size (Ternaux, 2012). The skeleton is made up of small glass particles, and is crack-resistant and stiff. The complexity, regularity and strength of their skeleton are astounding. To give a better idea of how strong this sponge can be, if you take an aluminum tube (aluminum and glass have similar elastic modulus) of equal length, effective thickness, and radius, and homogeneously distributed, it possesses just $1/100^{th}$ of the stiffness of this wondrous sponge (Aizenberg et al., 2004).

The Venus Flower Basket has already played an important role in the field of biomimicry, inspiring one of the most famous buildings in London, known as "The Gherkin." The architects and engineers based the structure of the building on the cylindrical shape of this sponge, granting the building much-needed

strength and resistance to strong winds while keeping material usage low. Another benefit of this design is its superior ventilation system. The placement of vents at the bottom of the building allows wind to easily wrap around the building's complex framework in a circular motion, bringing plenty of fresh air all the way to the top (Ternaux, 2012).

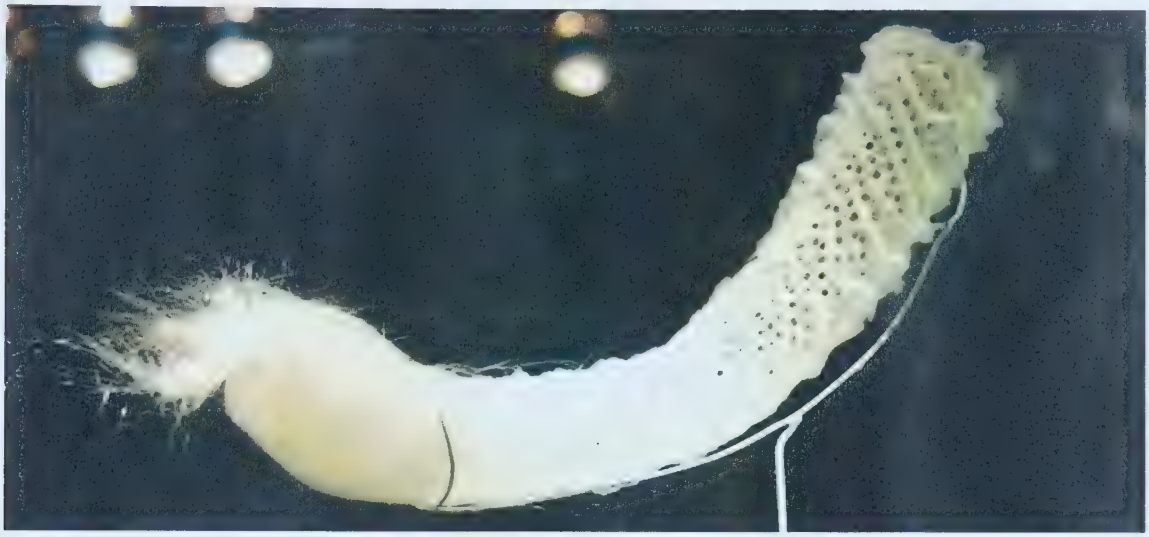

Figure 39 - Venus flower basket. Source: Ryan Somma, http://www.flickr.com/photos/ideonexus/2896278853/

Learning about the Venus Flower Basket reminded me of an experience I had at Nike. The Design Director for Tennis, Michael Hui, walked me through the process of how Nike had recently designed a sole that cut down on excess weight. In order to develop a lightweight and agile sole, they studied hundreds of shoes and marked the areas where they were most worn out. They then projected that data onto a 3D map of the foot, and pinpointed the areas of the sole that had little wear versus those that were constantly rubbing against the ground. Based on these observations, they eliminated a good portion of the sole rubber that basically had no contact with the ground, decreasing the weight of the shoe tremendously. This process imitates the Venus Flower Basket in that it uses form and material only where necessary, rather than implementing a standard, block structure that increases weight and detracts from aesthetics.

Another great example of a lightweight and resistant structure found in nature is the tree. Trees have highly impressive mechanical strength due to the fibres that run along the axis of the trunk and the branches. The fibres in the wood of tree trunks and branches are naturally-oriented in whatever direction which provides the greatest resistance to force, so trees are built to resist impact from natural

forces such as wind. A tree also distributes its material strategically. At the trunk and branch junctions, for example, it compensates for increased stress by increased thickness, which creates a strong foundation (Štefić et al., 2012).

Each of these examples shows how different systems achieve the same goal: increasing strength and resistance to force without adding bulk or weight. The architects involved in designing London's "Gherkin" building, as well as several designers at Nike, have already turned to nature for solutions to this problem. If more designers look to nature and mimic these effective structures in innovative ways, we will see unprecedented progress.

4.3 Vision

Vision is one of the most important senses for many species, including humans. Vision not only helps us see the beauty in life, it also helps us to navigate, locate danger, hunt, communicate, and basically recognize and understand the world around us. Thus, vision plays a crucial role in the decision-making process. When it comes to designing a car, the question that I posed earlier was how to remedy the problem of side mirrors that create dangerous blind spots. What can we learn from nature to develop better side mirrors that are free of blind spots, regardless of the shape of the car? I look at two interesting examples in nature that utilize vision to its maximum benefit.

Figure 40 – Chameleon eye. *Source: Umberto Salvagnin,* http://www.flickr.com/photos/kaibara/3845407728/

The first are chameleons. Chameleons are part of the lizard family. With over 150 different types, they are known for their many specialized functions, such as the ability to camouflage effectively by changing color to match their surrounding environment. Although these great species have no ears, they compensate for this with their advanced vision system. Each of their two eyes can function separately and simultaneously, allowing them to achieve 360° vision (Uhlenbroek, 2011). Their amazing eyes allow them to monitor their surroundings without moving, while remaining completely camouflaged. While hunting, chameleons are very difficult to notice, and are easily able to catch their prey without scaring them away thanks to their exceptional vision. Once one eye has located the prey, the viewpoints of both

eyes converge on it, providing binocular vision that enables the lizards to judge their distance from the prey accurately (Ott et al., 2001). Some modern cars strive to achieve such all-encompassing visual capabilities, and feature cameras that measure the area surrounding the car. This is especially useful when parking or moving in reverse. If this concept was also applied to side mirrors, and they also functioned as camera monitors that displayed and measured surroundings, many of the problems that result from blind spots could be avoided.

Figure 41 – Mantis Shrimp Eyes. *Source:* http://cdn.niketalk.com/3/36/900x900px-LL-3674b5e2_mantis.jp

Moving away from land animals and taking a dive into the ocean, we come across a sea-creature with extremely beautiful eyes, the mantis shrimp. The mantis shrimp has the most complex and complicated visual system of any living species. Just like chameleons, the shrimp have two eyes that can move independently of each other, but what makes them even more special is the level of detail present in their eyes (Uhlenbroek, 2011). Their eyes are divided into three regions, creating what is known as "trinocular vision," or vision that can track motion, form, color and depth (Matt, 2008). Understanding the sophisticated structure of these strips requires an explanation which is beyond the scope of this thesis. For our purposes, it is enough to examine the benefits of thee mantis shrimp's superior visual system.

Matt (2008) mentions that the mantis shrimp possesses the ability to see circular polarized light, which is similar to the effect we get when we put on 3D glasses in a 3D movie. Tsyr-Huei Chiou from the University of Maryland found that the eye of the mantis shrimp contains the only known cells in the animal kingdom that can detect such light. Our technology can do the same, but the mantis shrimps beat us to it by about 400 million years (Yong, 2008). These eyes also have the ability to see almost all kinds of color, ranging from ultra-violet to infra-red.

Some other amazing and interesting features related to vision exist in other animals. For example, the cuttlefish has amazing eyesight thanks to its pupils, which are shaped like the letter "w" rather than being round. Mandarin fish also have a very good color vision. Red-eyed tree frogs have a third eye lid which protects the eye and helps keep it clean. Tigers have the ability to see well at night because of a mirror-like layer that rests like a film over their eyes. And finally, the southern ground hornbill has eyelashes long enough to function as sunshades, protecting their eyes from the sun (Uhlenbroek, 2011). These are just a few interesting features and functions among thousands which man has yet to discover. Designers can learn a lot about innovation from exploring the depths of this wild and valuable unknown.

4.4 Moving Forward

Researching the different functions and features that could be adapted to product design has illuminated many different directions that I could take as a designer. For instance, as I continue to explore how to improve rigidity and flexibility in footwear and car seats, I have been studying sea cucumbers, whose skin is able to harden and soften according to exterior stimuli. This has led me to conceptualize an ergonomic style of footwear, with soles that change shape and adapt to changes in heat, pressure, and dampness. I have also analyzed features such as shape generation and how form works with function, and I plan to incorporate one or two of these new ideas into the final design case study of this thesis.

All these very different features, whether it is the material, structure, or the aesthetic quality of an object, play a very important role in the function it serves. It is important to understand that as much as nature has taught us and continues to teach us about efficient design, this is only the very beginning. The field of biomimicry is a fairly new one, and the features of nature are vast. Most of these functions are still undergoing more study to better understand how, exactly, each works. But incomplete knowledge should not stop designers from seeking inspiration from nature, and utilizing that inspiration and information in conceptual thinking and problem solving.

The challenge for me now is to collect and effectively integrate these different ideas and structures into innovative new systems and designs. I will start by re-evaluating each of my ideas, applying them to different case studies, and analyzing how nature can influence the outcome of my design, as well as my process and thinking. It is crucial to understand that ideas are often vague and full of flaws in their inception. It is only through trial and error and careful, critical thinking that a designer can lure the brightest ideas up from beneath the murky surface and bring true innovation to light.

5. Conceptual Implications

5.1 Case Study: Transportation

Figure 42 - nThree

Following the recent electric revolution of lightweight vehicles around the world, the following design is a case study in transportation design. With the irreversible process of global economies turning towards renewable energy, the way we see and use the city has already changed and is set to do so dramatically in the next few years.

With our increased awareness and sensitivity towards energy consumption, in the last 4-5 years, personal transportation has begun a slow but steady drift away from the model we have come to know in the past century. The new e-bikes and electric cars like the Renault Twizy or Toyota i-Road have shown the way to a more personal and conscious approach. This new concept, the nThree, builds on the characteristics and refines the strengths of these vehicles to bring electric power even closer to the mass market.

Even though the latest small electric are a great way to move around the urban areas, there is something about these offerings that could be improved, and that is price. Starting from about 7000

Euros and above these 1-2 seaters cost almost as much as a cheap standard car and more than many used ones in good condition.

nThree challenge

Small electric cars, tricycles and quadricycles all suffer from the same inherent drawback; they are meant to be cheap and affordable, but they end up being expensive like real cars because they are BUILT like real cars. The mission of the nThree was to address these conceptual and design shortcomings and design an affordable, single-seat electric vehicle that would offer all (or most) of the comforts of an electric car at the cost of an e-bike.

To achieve the objectives, the nThree was built with a simple approach reminiscent on the nCycle. In first place, the vehicle was reduced to the most stable geometry of three wheels to reduce cost.

Build. Unlike the Renault Twizy and the Toyota i-Road, the nThree does not have an expensive car-like transmission or a sophisticated rear wheel turning and power system. The power is discretely applied to the rear wheel only by means of an in-build motor, just like in many e-bikes while the steering is again very traditionally applied to the two front wheels.

A major objective in this design is to ensure light weight and strength, for better energy efficiency, speed, and safety. In order to do so, I re-visited one of the animals discussed in the previous chapter, the Toco Toucan, I try to re-apply the same functions and design principles used in its beak to the design. Observing the anatomy of the Toucans head, the principle is the same as any bird's beak, an upper and lower beak, both connected to one end keeping both parts in place. A simple "Y" shaped overall body structure will ensure a significant reduction in weight.

Figure 43- Toco Toucan, highlighting 3 main parts of the head. *Original image taken from:*
http://relevancy22.blogspot.com/2013/03/what-touconspeople-talk-about-when-they.html

Tilting and shock absorption. To provide a lighter and more effective shock absorption system, the whole structure of the nThree is split in two symmetrical parts compositing the "Y" shape, both merging at the rear wheel. The seat and steering are then mounted on this structure on four shock absorbers.

The whole assembly allows the vehicle to slightly twist while turning. Also, because of the split structure, the vehicle will have better stability in more hostile landscapes. Furthermore, each bump and road irregularity that affects one of the front wheels will travel to the rear wheel and then to the other side of the vehicle, providing double the length for much better shock absorption.

Figure 44 - Highlighting the similarities to the toucan beak overall head anatomy.

Figure 45 - Connection of two side arms at the back

The side arms are internally shaped and modeled like a toucan beak; the two side arms have a thin and lightweight section which is also strong to shock and impacts. In order to mimic this functionality, I ran a stress analysis test on the side arms of the design to figure out the areas being stressed out most on the body, and to try to better distribute the stress based on the profile shape of the arm and the different areas it connects with the other parts of the design.

I cut a section of the side arm and analyzed the bending of the arm. The stress analysis test showed higher stress levels closer to the places that apply force to the arms; such as the middle seat section or when a person actually sits inside the trike and interacts with it.

The red colors represent the areas with the most stress, while the blue regions have the least stress. The idea is to use three layers to make up the side arms, just as it is in the Toucan's beak. The whole body will be covered with carbon fiber material. The green to red regions will fill the inside of the arms with foam material, while the blue regions will remain hollow to help with weight reduction. The foam that will be used needs to be further evaluated by a material engineer to evaluate different strength levels, but from a design point of view, I am considering something like the Venus Flower Basket structure, which looks similar to what is found inside a toucan's beak would be an interesting material to use for the foam. The distribution of the material based off the stress analysis test would be as follows:

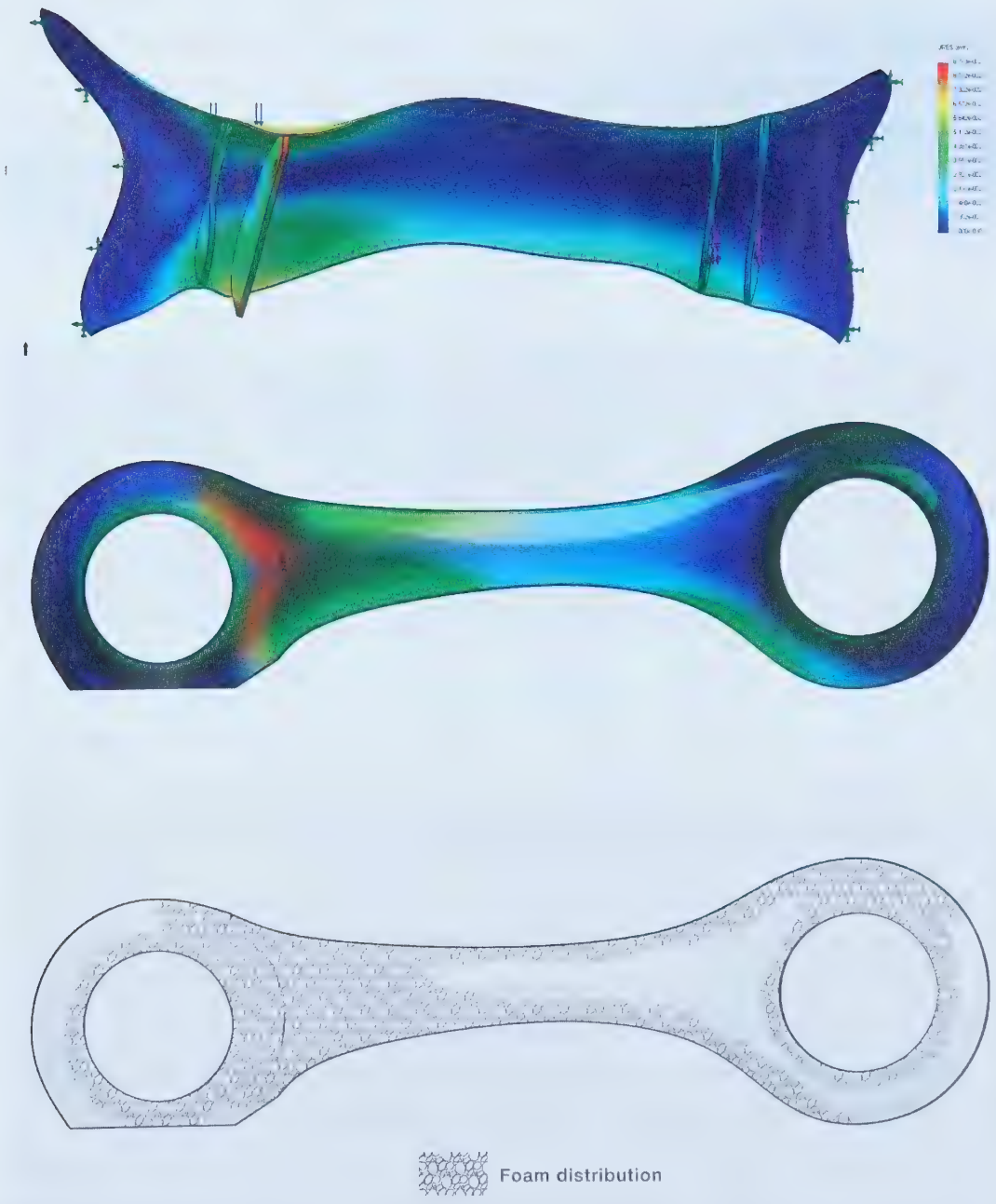

Figure 46 - Illustration of body with foam distribution

Seat. The seat as well, follows the same concept of the Venus Flower Basket, it is also designed by cutting away parts that do not affect the driver nor the aesthetic, while still keeping it strong and functional. It includes several openings and reinforced, oversized sections to be as light as possible and ensure the driver's safety. Compared to similarly proportioned vehicles weighting about 300-500Kg, the nThree is expected to weight only around 100 Kg or less depending on the materials and hardware used. This will translate in a much higher power efficiency and lower energy consumption.

Figure 47 - nThree Seat

Removable cover. Because the nThree is a hybrid between an e-bike and an electric car, it will provide a lightweight, removable cover to shade the driver from the sun or protect it from the rain and wind. Unless the driver chooses to put the cover on, driving the nThree will be just as fun and ventilating as riding a bicycle.

The nThree is a project that approaches innovation from the very beginning, and works around the concept of innovating throughout the whole process. The final outcome of this project has clearly benefited from looking towards nature for innovative solutions to better answer the challenge set in the beginning and elevated the overall design. Looking at the nThree, it houses innovations inspired from nature and other places, and to me biomimicry should not limit any designer to be inspired or to reference things outside of nature while answering a brief or solving a design problem. Designing the nThree has definitely been an interesting and beneficial project for me as a designer to be involved with.

Below are the final designs from the nThree project:

Figure 48 - nThree side view with cover

Figure 49 - nThree side view without cover

Figure 50 - nThree front view with cover

Figure 51 - nThree back view with cover

Figure 52 - nThree front view without cover

Figure 53 - nThree back view without cover

Figure 54 - nThree

Figure 55 - nThree top view

Figure 56 - nThree

6. Summary & Conclusions

Inspiration and innovation are essential to all designers and creative minds, and they are symbiotic concepts as innovation grows out of inspiration, and often results in new inspiration and further innovation. Throughout this thesis I examined many examples of great products and extremely talented designers who discussed their methods of finding inspiration and reaching different levels of innovation. I also expanded my horizons in the quest for inspiration by travelling to foreign countries, collaborating with other designers, and then putting my ideas to the test with the nCycle as well as the nThree case study. Understanding the many ways to find inspiration and achieve innovation, I have learned that true innovation cannot be attained without first locating a source of true and limitless inspiration; nature is one of the greatest, most accessible sources of such inspiration for a designer. Nature, and the field of biomimicry in general, have captured my interest because of the dynamic creativity they inspire. The point of biomimicry is not to copy nature, but to collect ideas from the natural world and allow them to evolve, to fuse and connect in unique ways, ultimately resulting in ground-breaking product designs.

Nature is an unrivaled source of inspiration because of its endless variety, aesthetic beauty, and ecological efficiency. It offers endless lessons in sustainability, as all of its systems are completely self-sufficient and avoid unnecessary waste. These are crucial lessons for mankind as we enter an era of severe environmental crises caused by our own lack of ecological awareness and efficiency. What makes nature so unique is that on top of its near-perfect functionality, the natural world provides stories. During my three-month internship at Nike, I acquired tremendous knowledge about the essentials of story-telling in product design and marketing. When a product tells a story, consumers are better able to understand the full benefits of the features of a product, and the story becomes an effective promotional tool. It did not take long for me to realize that applying natural functions to product design provides endless story-telling opportunities. For instance, a car that can regulate temperature according to the weather, or that can withstand severe impact without increasing in bulk, becomes fascinating as well as functional when one learns that these features were developed by studying the beak of the toucan.

To be true to my findings, as exciting as I found the field of biomimicry and observing nature, as a designer I sometimes found focusing solely on nature difficult. Not being an expert in biology or ecology, I often found it challenging to find solutions to crucial design problems simply by observing nature. Regardless of how inspired I would get, which was crucial and necessary, I felt at times that I needed

more explanation of how or why some things worked. This often required some very extensive reading, research, and experimentation, as well as endless searching for answers that have not yet been answered by scientists. I would sometimes witness some amazing functions in nature that I had no use for, or I had some great ideas that I found no match for in nature, although I was sure a match existed somewhere. So I tried to work with the existing processes in the field of biomimicry: the solution-based approach and the problem-based approach. The first begins with a series of solutions, then actively seeks problems to which they could be successfully applied, while the latter begins with a problem, then seeks appropriate solutions through trial and error. I found that it was most efficacious for me to utilize both of these methods by combining them into one process, in which I would keep a log of all the problems and solutions I encountered. When I found an impressive function in nature, I wrote it down, so even if it did not solve any of the existing problems I was working with, I have it on record and it can be easily accessed and applied to design problems I may face in the future. Not only does this make it easier for me to match functional solutions to design issues, it helps me to better understand how these functions work both singularly and in conjunction to create more innovative and progressive solutions.

Similarly, I have studied bio-inspired products that already exist, and have experimented with applying the same applications and functions they have to different products in different ways, mimicry with a twist, which can result in an entirely new way of understanding a product. I consider this method to be a form of collaboration, as I am utilizing the ideas and work of other designers. One of the major lessons I learned at Nike was the importance of collaboration in developing innovative and fresh designs. Not only do two heads contain more ideas than one, when those ideas collide, they evolve in unexpected directions, and the possibilities are limitless. Also more important is the practice of looking, exploring, documenting and being open to the to the different practices and environment around us.

Perhaps then, the most important lesson I have learned, both at Nike and through my own work, is that the creative mind must never rest. Inspiration is like oxygen to a designer; without it, the imagination withers up and dies. Inspiration can certainly come from nature, but that is not the only source. As I explained above, collaboration also results in innovation. And so does travel. After talking to several Nike employees who had taken "inspiration trips" to different countries to study the practices and principles of different cultures, I was inspired to take my own trip. I spent several weeks travelling through the Middle East to study traditional art forms with local masters, which proved to be one of the best decisions I have ever made. It transformed my perspective and approach in many ways. For instance, observing how palm leaves can be used to make everything from baskets to shelter to paper

has had an unprecedented impact on my understanding of sustainability, and thus on my goal of incorporating "green" elements in all my design projects. Exploring different corners of the world has allowed me to see the world in different ways.

Through all my research, some of the wisest and most inspiring ideas I have encountered have been those of Frans Johansson. Johansson developed the concept of the "Medici Effect," and has written extensively on the innovation that results when different ideas intersect. While Johansson's work focuses on the intersection of ideas that arise from different cultures and ideologies, I am inspired to apply this theory to the design world. What will happen when different functions that exist independently in nature collide during the design process? What solutions are possible when existing innovations intersect in unexpected and unimagined ways? How can one natural feature revolutionize a product that already exists? The raw materials that nature provides are limitless. So are the possibilities. As I take all that I have learned from my experience at Nike, my travels, and my design projects, and merge it all together cohesively into a thesis, I am truly inspired and excited. Nature has provided me with more tools than I ever imagined could exist, and this is only the beginning. All of these experiences have taught me the value of inspiration, and opened my eyes to its ubiquitous nature. I am confident that as I progress in my career as a designer, both the world around me and the scope of my ideas will continue to grow and expand in exciting ways. I anticipate a future full of innovation.

7. Bibliography

Ackerman, E. *The histogenesis of hair follicles in the zebra and giraffe with special reference to pigmentation and cutaneous vasculature.* University of Pretoria: Unpublished MSc Dissertation, 1976.

Aizenberg, Joanna, Vikram C. Sundar, Andrew D. Yablon, James C. Weaver, and Gang Chen. "Biological glass fibers: Correlation between optical and structural properties." *PNAS* 101, no. 10 (2004): 3358–3363.

Barnes, Cathy, et al. *Biomimetics: strategies for product design inspired by nature.* Report of a DTI Global Watch Mission, London, UK: Department of Trade and Industry,, 2007.

Bechert, D. W., M. Bruse, W. Hage, and R. Meyer. "Fluid mechanics of biological surfaces and their technological application." *Naturwissenschaften*, 2000: 157-171.

Ben-Ari, E. "Geckos yield their sticky secret." *BioScience* 52, no. 10 (2002): 960.

Benyus, Janine M. *Biomimicry, Innovation Inspired by Nature.* 1997.

Bodde, SG, MA Meyers, and J. McKittrick. "Correlation of the mechanical and structural properties of cortical rachis keratin of rectrices of the Toco Toucan (Ramphastos toco)." *Journal of the Mechanical Behavior of Biomedical Materials* 4, no. 5 (2011): 723-732.

Boks, Casper, and Nina Louise Volstad. "On the use of Biomimicry as a Useful Tool for the Industrial Designer." *Sustainable Development* 20, no. 3 (2012): 189-199.

Buss, Irven O., and James A. Estes. "The functional significance of movementsand positions of the pinnae of the African elephant (Loxodonta africana)." Edited by Irven O. Buss and James A. Estes. 52 (1971): 21-27.

Capadona, J, K Shanmuganathan, D Tyler, Stuart J. Rowan, and Christoph Weder. "Stimuli- responsive polymer nanocomposites inspired by the sea cucumber dermis." *Science* 319 (2008): 1370–1374.

Cengel, Y. A., and J. M. Cimbala. *Fluid Mechanics: fundamentals and applications.* New York: McGrawHill, 2010.

De Beaufort, L.F. "On a case of correlation between blood vessels and colour pattern in a giraffe." *Tijdschrift der Nederlandsche Dierkundige Vereeniging* 3 (1927): 31-32.

Docksai, Rick. "Biomimicry to Fight Blindness." *The Futurist*, September/October 2011: 18-19.

Dugan, David. "Inside Nature's Giants." Harpercollins, 2011.

Eadie, Leslie, and Tushar K. Ghosh . "Biomimicry in textiles: past, present and potential. An overview." *Journal of the Royal Society*, 2011.

Eggermont, Marjan. "Biomimetics as problem-solving, creativity and innovation tool." *Proceedings of CDEN/C2E2 Conference: University of Manitoba.* Manitoba: Canadian Engineering Education Association, 2007.

El-Zeiny, Rasha Mahmoud Ali. "Biomimicry as a Problem Solving Methodology in Interior Architecture." *Procedia - Social and Behavioral Sciences* 50 (2012): 505-512.

Fecchio, R.S., et al. "Mechanical behavior of prosthesis in Toucan beak (Ramphastos toco)." *Materials Sceicne and Engineering C* 30 (2010): 460-464.

Gatesy, John, Cheryl Hayashi, Dagmara Motriuk, Justin Woods, and Randolph Lewis. "Extreme diversity, conversation, and convergence of spider silk fibroin sequences." *Science* 291, no. 5513 (2001): 2603-2605.

Ghahremani, Yasmin. "The World's best minds in R&D." *Corporate Knights*, Summer 2012: 30-36.

Hargens, Alan R., Ronald W. Millard, Knut Pettersson, and Kjell Johansen. "Gravitational haemodynamics and oedema prevention in the giraffe." *Nature* 329 (1987): 59-60.

Helms, M., S. V. Swaroop, and A. K. Geol. "Biologically inspired design: Processs and product." *Design Studies* 30 (2009): 606-622.

Hilsberg, S. *Aspekte zur klinischen Anwendung der Infrarot-Thermographie in der Zoo- und Wildtiermedizin.* PhD Dissertation, Faculty of Veterinary Medicine, University of Leipzig, 2000.

Johansson, Frans. *The Medici Effect.* Cambridge: Harvard Business Review Press, 2006.

Klir, John J., James E. Heath, and Naima Bennani. "An infrared thermographic study of surface temperature in relation to external thermal stress in the Mongolian gerbil, Meriones unguiculatus." *Comparative Biochemistry and Physiology Part A: Physiology* 96, no. 1 (1990): 141-146.

Lacey, EP, ME Lovin, SJ Richter, and DA Harrington. "Floral reflectance, color, and thermoregulation: what really explains geographic variation in thermal acclimation ability of ectotherms?" *The American Naturalist* 175, no. 3 (March 2010): 335-349.

Lang, A. W., P. Motta, P. Hidalgo, and M. Westcott. "Bristled shark skin: a microgeometry for boundary layer control?" *Bioinspiration & Biomimetics* 3, no. 4 (2008).

Langman, V.A. "Cow-calf relationships in giraffe (Giraffa camelopardalis giraffa)." *Zeitschrift fur Tierpsychologie* 43 (1977): 264-286.

Matt, Ransford. *Popular Science Magazine: The Eye of the Mantis Shrimp.* March 21, 2008. http://www.popsci.com/scitech/article/2008-03/eye-mantis-shrimp/ (accessed April 10, 2013).

McDonagh, Sorcha. "Caught on tape: Gecko-inspired adhesive is superstrong." *Science News* 163, no. 23 (2009).

McDonough, W., and M. Braungart. *Cradle to Cradle - Remaking the Way We Make Things.* New York: North Point Press, 2002.

McKittrick, J, P.-Y Chen, S. G. Bodde, W. Yang, E. E. Novitskaya, and M. A. Meyers. "The Structure, Functions, and Mechanical Properties of Keratin." *JOM* 64, no. 4 (2012): 449-468.

Midtgård, Uffe. "Blood vessels and the occurrence of arteriovenous anastomoses in cephalic heat loss areas of mallards, Anas platyrhynchos (Aves)." *Zoomorphology* 104 (1984): 323-335.

Mitchell, G., and J. D. Skinner. "On the origin, evolution and phylogeny of giraffes Giraffa camelopardalis." *Transactions of the Royal Society of South Africa* 58, no. 1 (2003): 51-73.

Mitchell, G., and J.D. Skinner. "Giraffe thermoregulation : a review." *Transactions of the Royal Society of South Africa* 59, no. 2 (2004): 109-118.

Narasimhan, A. "Why do Elephants have Big Ear Flaps?" *Resonance* (Indian Institute of Technology), 2008: 638-647.

Page, RA, and MJ Ryan. "Social transmission of novel foraging behavior in bats: frog calls and their referents." *Current Biology* 16, no. 12 (2006): 1201-1205.

Pailhas, Y., C. Capus, and K. Brown. "Dolphin-inspired sonar system and its performance." *Radar, Sonar & Navigation, IET* 6, no. 8 (2012): 753-763.

Papanek, Victor. *Design for the Real World: Human Ecology and Social Change.* Chicago: Academy Chicago Publishers, 1971.

Pedersen Zari, M., and J. B. Storey. "An Ecosystem Based Biomimetic Theory for a Regenerative Built Environment." *Sustainable Construction, Materials and Practices: Challenge of the Industry for the New Millenium.* Lisbon, Portugal: in-house publishing, 2007.

Priesnitz, Wendy. "Biomimicry: Inspiration From nature for solving human problems." *Natural Life Magazine*, July/August 2012.

Quinn, Sonya, and William Gaughran. *Bionics - An inspiration for intelligent manufacturing and engineering.* 2010.

Reap, John. *Holistic Biomimicry: A Biologically Inspired Approach to Environmental Engineering.* A Dissertation Presented to The Academic Faculty, Atlanta: Georgia Institute of Technology, 2009.

Roberts, B. S., K. S. Kamel, C.E. Hendrick, S. O. McLean, and R. L. Sharp. "Effect of a FastSkinTM suit on submaximal freestyle swimming." *Medicine & Science in Sports & Excercise* 35, no. 3 (2003): 519-524.

Samuelson, Marcus. *Yes, Chef: A Memoir.* Random House Trade Paperbacks, 2012.

Schoeller®. *The Bionic Climate Membrane.* December 15, 2006. http://www.schoeller-textiles.com/uploads/media/cchange_e.pdf (accessed April 10, 2013).

Scott, G. R., V. Cadena, G. J. Tattersall, and W.K. Milsom. "Body temperature depression and peripheral heat loss accompany the metabolic and ventilatory responses to hypoxia in low and high altitude birds." *The Journal of Experimental Biology* 211, no. 8 (2008): 1326-1335.

Seeley, Thomas D. *Honeybee Democracy.* Princeton: Princeton University Press, 2010.

Skinner, J. D., and R. H. N. Smithers. "The mammals of the Southern African Sub-region, 2nd Edition." 604-607. 1990.

Stamps, Penny W. *Nature's Industry: The Role of Biomimicry in the New Green Economy.* 2010.

Star, Toronto. *Cars mimicking nature is no bird-brained idea.* November 28, 2009. www.wheels.ca/news/cars-mimicking-nature-is-no-bird-brained-idea/ (accessed February 12, 2013).

Štefić, Tihomir, Jurić Aleksandar, and Pavao Marović. "Experimental analysis of combined action of bending, shear and torsion on timber beams." *Technical Gazette* 19, no. 3 (2012): 653-658.

Tattersall, G. J., D. V. Andrade, and A. S. Abe. "Heat Exchange from the Toucan Bill Reveals a Controllable Vascular Thermal Radiator." *Science* 325, no. 5939 (2009): 468-470.

Ternaux, Elaodie. *Industry of nature; Another approach to ecology.* Amsterdam: Frame Publishers, 2012.

Uhlenbroek, Charlotte. "Animal Life." 124-125. New York: Dorling Kindersley, 2011.

Van der Brugge, A.J.N. *Biomimicry for Light Regulation in Building Envelopes Polarization for glare reduction & visual comfort.* June 22, 2010. http://repository.tudelft.nl/view/ir/uuid%3Aecc7563f-3ac0-44c5-a963-957fc1403d6a/ (accessed March 24, 2013).

Vincent, Julian F.V., Olga Bogatyreva, Anja-Karina Pahl, Nikolay Bogatyrev, and Adrian Bowyer. "Putting Biology into TRIZ: A Database of Biological Effects." *Creativity and Innovation Management* 14, no. 1 (2005): 66-72.

Vollrath, F., and DP Knight. "Liquid crystalline spinning of spider silk." *Nature* 410 (2001): 541-548.

Wang, Q. "Breakthroughs in the water: science of swimming." *Yale Science Magazine*, 2004: 19-21.

Yong, Ed. *Science Blogs: Not Exactly Rocket Science.* March 21, 2008. http://scienceblogs.com/notrocketscience/2008/03/21/mantis-shrimps-have-a-unique-way-of-seeing/ (accessed April 10, 2013).